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25-28 June 2016 - Budapest, Hungary

PROCEEDINGS

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Automation and Robotics in Construction

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A Mechatronic Slip Complex Control when Erecting Monolith Objects

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Abstract

The paper considers the principles of a mechatronic slip complex (MSC) control for monolith construction, which features the availability of two groups of effectors requiring coordinated work. It has been shown that for the MSC control it is advisable to use a two-level structure; the upper level tasks of which are planning the complex hoisting and synchronizing the operation of control mechanisms, while the tasks of the lower level incorporate the development of control signals formed at the previous level. In order to remove the complex deviation from the designed location it is suggested to apply the method of the MSC movements planning with due account of limitations for control and effects of disturbing influences on the structure being erected.

Keywords: monolith building, slip forms, automation, mechatronic complex, control.

1. Introduction

Construction of monolith objects is connected with great labor effort and multiple adjusting operations especially when erecting structures with varying cross-section and walls width. The analysis of monolith construction technology has shown the expediency of designing mechatronic complexes on the basis of slip forms as they provide automation of the project erection with continuous-cyclic placement and consolidation of concrete. Consideration of different variants of the MSC development on the basis of slip forms has led to the idea of using a movable platform 1 bearing against columns 2 with help of lifting posts 3 which are equipped with jacks 4 (Figure 1). The forms 5 are suspended from the platform by means of radial displacement mechanisms (RDM) 6 thus providing for the adjustment of panels location. For the purpose of lifting it is advisable to use frequency control electromechanical jacks, which allows to adjust hoisting speed and to synchronize movement. For the RDM it is preferable to use an induction motor drive with relay control. The main tasks of the mechatronic complex control are to lift the platform with forms during the process of concrete placement, change panels location when lifting, adjust the platform position when shifts or torsions occur, and synchronize the equipment operation.

Taking into account the complexity of MSC as an object of control, a great number of disturbing and adjusting influences and control limitations it is of interest to consider the problems of the complex control which include planning its motions, development of the laws of control, and solution of the problem of mechanisms operation synchronization. As opposed to known designs and systems fully automated lifting of slip form is offered [1-9].

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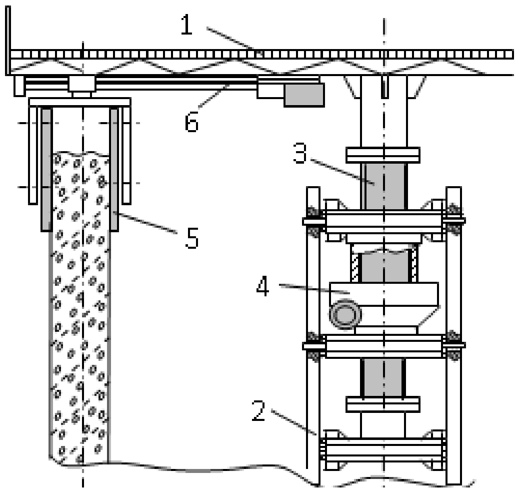

Figure 1. Slip form: 1 - movable platform; 2 – column; 3 - lifting post; 4 - electromechanical jack; 5 – form; 6 - radial displacement mechanism

2. Characteristic features of the MSC control

The distinctive feature of the MSC is the availability of two groups of effectors: hoisting jacks and RDM that require coordinated operation. During the process of operation the jacks experience considerable static and dynamic loads which are irregularly distributed in the jacks. When the platform lifts, the load changes due to concrete – panels interaction (Figure 2).

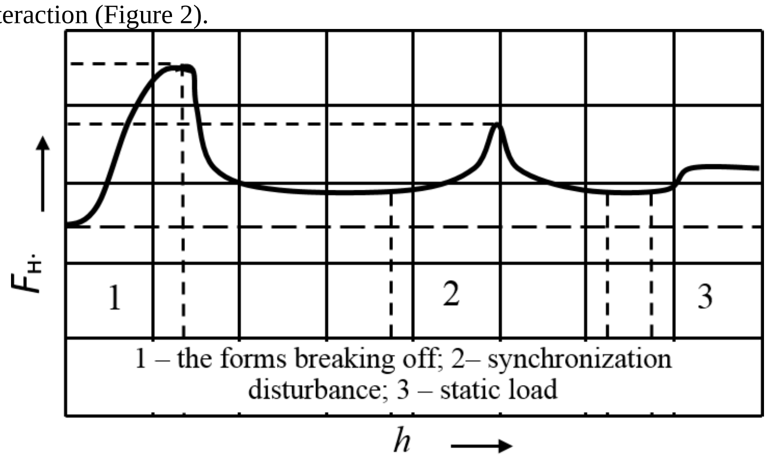

Figure 2. The load changes on the slip platform

During the operation irregularity of hoisting the jack loads can be up to 75-86%, which results in a violation of the platform horizontal displacement, its deviation from the designed axis and twisting of the platform with forms. Such operation condition of hoisting jacks make stringent requirements to drives and causes the necessity to synchronize lift speeds.

RDM operation is under the influence of friction and elastic forces appearing with the deformation of the forms elements. When the synchronization of the operation of hoisting and adjusting units is broken, reaction forces in concrete additionally act on the RDM, and they have a non-linear character (Figure 3). This causes an increase of load and decrease of the mechanism speed. Therefore, the operation of the RDM drives should be strictly synchronized with the platform hoisting and agreed with the curvature of the walls being erected.

The process of the MSC operation is accompanied by disturbing influences. They are caused by sunlight heating and wind loads [1]. Actions of heat and wind loads can result in considerable deviations in the MSC operation and they must be taken into account when developing control algorithms. Net deviations should be considered as a sum of deviations due to heating (x_t, y_t) and wind deformation of the structure (x_w, y_w):

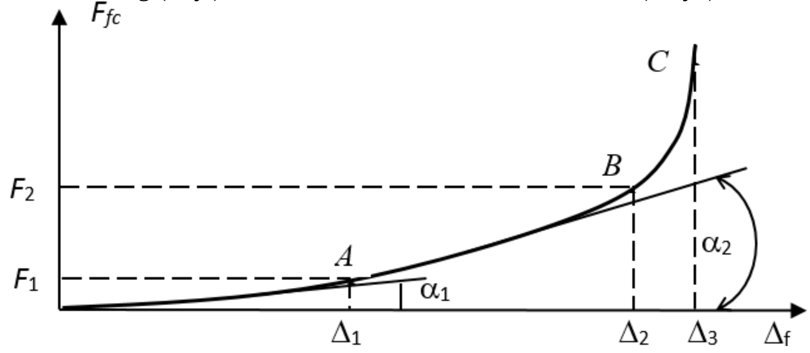

Figure 3. The reaction forces of concrete: F_{fc} - force of reaction; Δ_f - deformation of form

$$x_\Delta = x_H + x_W = \delta_H \cos\alpha_H + \delta_W \cos\alpha_W;$$
$$y_\Delta = y_H + y_W = \delta_H \sin\alpha_H + \delta_W \sin\alpha_W,$$

where $\alpha_H = \psi(t)$ is the direction of sunlight heating; α_W is the direction of wind; $\delta_H = f_1(\Delta\tau, h, \alpha_H, \nu_W)$ is heat deformation; $\delta_W = f_2(h, \sigma_W, \nu_W)$ is wind deformation; ν_W is wind velocity; $\Delta\tau = \tau_H - \tau_C$ is difference in temperature between sunny and shady sides of the object; h is the complex elevation.

The platform turn caused by actions of external factors can be conveniently related with the coordinates of hoisting mechanisms by the following equations:

$$\alpha_g = arctg\left[\max\left(\Delta z_j^{(i)}\right)/R_j\right]; \quad \beta_g = \frac{2\pi}{n} i\left[\max\left(z_j^{(i)}\right)\right];$$

$$\psi_g = \frac{1}{n}\sum_{i=1}^{n}\left[arctg(C) - \frac{2\pi}{n}(i-1)\right];$$

$$C = \left(y_j^{(i)} - \frac{\sum y_j^{(i)}}{n}\right) \Bigg/ \left(x_j^{(i)} - \frac{\sum x_j^{(i)}}{n}\right),$$

where α_g, β_g are the angle and the direction of inclination; ψ_g is a platform torsion; R_j is the radius of jacks arrangement.

The characteristic feature of the MSC control is control limitations connected with structural features and technological control cycles. Maximal inclination of the platform with forms in a hoisting step cannot exceed the conicity of the forms panels. Maximal deviation of jacks' travel from the average hoisting step value is limited by the magnitude:

$$\Delta h_{\max} = \left|\left(h_j^{(i)}\right)_{\max} - \frac{\left(\sum h_j^{(i)}\right)}{n}\right| \le \frac{\Delta D_j l_b}{2},$$

where Δ is a clearance at the bottom of the forms' panels; l_b is panels height.

Therefore, to control the MSC it is necessary to provide the measurement and compensation for wind and temperature influences upon the erected object. The complex lift control should be carried out with due account of limitations for controllability and provision for the trajectory minimal curvature. We suggest to correct the the platform position by inclining it in the direction opposite to the displacement; in order to eliminate the platform torsion it is suggested to use the backward wave method which resides on the sequential change of the platform inclination direction in each step of hoisting. As a result there appears a spiral motion of the forms in the direction opposite to torsion. This kind of control is based on the forms mathematical model that allows to combine complex condition parameters with controlling and disturbing influences.

3. Movements planning and the MSC control

When solving the tasks of control we consider the MSC as a completely observable multidimensional object having limitations for controllability. The complex control provides for the correction of the platform position in the process of hoisting. Proceeding from the complex features and properties we have chosen a two-level structure so as to control it [2]. The tasks of the upper level are the planning of complex movements with view of limitations for control and disturbing influences. Taking into consideration the intricacy of the complex control we suggest to plan movements by simulating the MSC hoisting with due account of the current condition, affecting disturbances and influence casual factors. The tasks of the upper level of control also comprise the formation of control actions and synchronization of the mechanisms motions. The tasks of the lower (executive) level include the development and refinement of control signals. Such structural organization of the MSC control allows us to achieve the pre-set quality of control and the required accuracy.

One of the main tasks of control is to plan the movements of the MSC, which incorporates movement trajectory development and formation of the control laws for lifting and adjusting mechanisms on its basis [3]. The trajectory for the platform and forms lifting is planned so that to eliminate the developed deviations by the end number of steps, to locate the platform on the designed axis and to ensure its horizontal position. Taking into consideration a monotonic character of the desired trajectory, smoothness requirements for the transitional trajectory and also restrictions for curvature determined by the conicity of the forms panels, the planned movement trajectory can be represented by two datum functions:

$$\delta(l) = \begin{cases} a_{12} l^2 + a_{11} l + a_0, & l < l_s \\ C_{21} e^{\lambda_{21}(l - l_s)} + C_{22} e^{\lambda_{22}(l - l_s)}, & l \geq l_s \end{cases}$$

where $C = [C_k]$ is a vector of the parameters being determined; $l_s = \left(b_1 + \sqrt{b_1^2 + 2\gamma b_0}\right) / \gamma$ is a conjugation point of the trajectory sectors.

To control the complex we determine coordinates of points $x_g^{(k)}, y_g^{(k)}$ and inclination angles $\alpha_g^{(k)}$ of the platform at the end of each step of lifting: $x_g^{(k)} = \delta(l_k)\cos\beta_g$, $y_g^{(k)} = \delta(l_k)\sin\beta_g$, $z_g^{(A)} + l_k$, here $l_k = k\,h_p$ is the height of lifting from the beginning of correction; $z_g^{(A)}$ is an altitude position of the MSC at the beginning of correction; h_p is step of lifting. The coordinates of the planned trajectory points at the end of each hoisting step are corrected with due account of temperature and wind deformation of the object:

$$\begin{cases} x_{tr}^{(k)} = x_g^{(k)} - x_\Delta^{(k)} = \delta(l_k)\cos\beta_g - \delta_H(l_k)\cos\theta_H - \delta_W(l_k)\cos\theta_W, \\ y_{tr}^{(k)} = y_g^{(k)} - y_\Delta^{(k)} = \delta(l_k)\sin\beta_g - \delta_H(l_k)\sin\theta_H - \delta_W(l_k)\sin\theta_W. \end{cases}$$

Taking into consideration kinematic and dynamic features of the mechatronic complex its control is developed on the basis of kinematic algorithms. The laws of time variation of the complex phase coordinates and its space location relative to the designed axis are described by the system of equations in the form of:

$$\begin{cases} z_g(t) = \sum_{i=1}^{k-1} h_g^{(i)} + \int_0^t v_g^{(k)} dt, \\ x_g(t) = \delta_g(l_k)\cos\beta_g - x_{sb}^{(k)}, \\ y_g(t) = \delta_g(l_k)\sin\beta_g - y_{sb}^{(k)}, \\ r_{mr}(t) = \sum_{i=1}^{k-1} r_{mr}^{(i)} + K_\varphi \int_0^t v_{pl}^{(k)} dt. \end{cases}$$

Adjustment of the platform position is a long process running through many steps of the MSC lifting, so it is convenient to calculate the platform inclination within a step on the basis of recurrent relationships:

$$\begin{cases} \alpha_g^{(k+1)} = \alpha_g^{(k)} + arctg\left(a_1 + 2a_1 l_k + \Delta l\right), & l < l_s \\ \alpha_g^{(k+1)} = \alpha_g^{(k)} + arctg\left(\lambda_1 C_1 e^{\lambda_{21}\xi} + \lambda_2 C_2 e^{\lambda_{22}\xi}\right), & l < l_s,\ \xi = l_k + \Delta l - l_s. \end{cases}$$

The platform inclination angles $\alpha_g^{(k+1)}$ and $\beta_g^{(k+1)}$ being calculated during the process of motions design are used for forming lift value $h_i^{(k+1)}$ of each jack:

$$h_i^{(k+1)} = h_p + \Delta h_i^{(k+1)} = h_p + R_j \sin\left(\alpha_g^{(k+1)}\right)\cos\left(\frac{2\pi}{n} i + \beta_g\right).$$

Control actions $r_{rj}^{(k+1)}$ of mechanisms for radial displacement are calculated in each step of hoisting on the basis of high-altitude position of the platform $z_g(t)$, shift relative to the design axis x_g, y_g and with due account of inclination angle α_g. Moreover, the radius change of each MRD is synchronized with level of the platform position:

$$r_{rj}^{(k+1)}(t) = K_{mr} v_j t + x_g \cos\varphi_j + y_g \sin\varphi_j,$$

where $r_{rj}^{(k+1)}$ is radius change caused by the platform shift; φ_j is an angle of the j-th MRD location.

Control actions $h_i^{(k+1)}$, $r_{rj}^{(k+1)}$ are developed by the lower level of control uniting local control devices for hoisting units and mechanisms of radial displacement. Hoisting jacks control differs in using frequency induction drive with synchronization of operation. A hoisting jack (HJ) drive control must provide for the execution of a hoisting step with a pre-set speed and a smooth speed adjustment. The characteristic feature of the HJ drives is a high accuracy of control in a wide range of load change. Considering the analysis results of the drive dynamic properties the preference should be given to the system of a subordinate HJ control comprising the main speed circuit and the inner subordinate current circuit. Synthesis of the HJ drives regulators is performed by the method of a step-by-step correction with subordinate control. Factors calculation for exterior and interior circuit is performed for static modes of operation on the basis of the developed technique.

Characteristic feature of the MRD drive is that it has a three-position control with feedback in terms of position. In order to synchronize the operation of the MRD and the HJ a recurrent-transitory mode of drive operation is used; it meets strict requirements to the quality of control. Analysis of dynamic properties of the MRD has shown that the presence of a relay element results in the vibrating transient process connected with drive inertia. To improve dynamic properties of the drive we have developed a correction method according to which we first calculate the drive run-out value for the rated speed:

$$\delta_{ro}(t) = V_{mr}^{(nom)} T_{mr}\left(1 - \exp\left(-\frac{t}{T_{mr}}\right)\right) = 0{,}999 V_{mr}^{(nom)} T_{mr},$$

where $V_{mr}^{(nom)}$ is rated speed of the MRD; T_{mr} is time constant of the MRD. Then, according to $\delta_{ro}(t)$ we define structure and parameters of correcting device. As a result of synthesis we obtain a transfer function of correcting feedback

$$W_{cd}(s) = \frac{K_{cd} s}{T_{cd} s + 1},$$

where K_{cd} and T_{cd} are transfer coefficient and time constant of the correcting device determined by the value of drive run-out.

4. Conclusion

The described method of control makes the basis of algorithms for the form automatic control system. The difficulty of controlling a mechatronic complex is connected with the fact that it takes a lot of time to correct mistakes that occur during the process of lifting. Their elimination is only possible after 10-20 steps of lifting. Therefore it is necessary to forecast the behavior of the complex system under control on the basis of mathematical description with applying laws of control. The lifting trajectory for the platform and forms is planned so that to eliminate arisen deviations through the end number of steps, to maintain the platform along the designed axis and to ensure its horizontal position. The control influences formation is carried out on the basis of planning algorithms considering heat and wind impacts on the erected object. In the construction of industrial facilities the control accuracy of the mechatronic slip complex is 50 mm with the formwork lifting speed up to 12 m in 24 hours. The quality of the concrete surface eliminates the need for additional finishing, which saves effort and material consumption in construction works.

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Air Conditioning Ducts Inspection and Cleaning Using Telerobotics

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Abstract

This paper focuses on the importance of having clean air conditioning duct and its influence on our lifestyle. Firstly, we study health norms and memorandums that emphasize on the hygiene factors and metrics in certain building and habitats then we analyze the possibility of using telerobotic solution in order to improve the cleaning process of the air ducts by automating the cleaning process, removing debris and dust. The telerobotic solution consists of a mobile robot based on BioVac systems, armed with manipulator and spray guns. The positioning of the BioVac robot is controlled using fuzzy logic algorithm.

Keywords: duct cleaning, site management, telerobotics.

1. Introduction

Air and water quality are one of the major elements directly affecting human being. Therefore, historically, most conflicts sparkled in order to acquire healthy and fertile lands. The evolution of the humanity imposed changes to life styles and habitations. With population growth, lands have become luxurious and rare resources. In parallel, importing enough water and services to habitats such as building drainage, water supplies and roads became traditional social and technical problems to deal with.

Many technologies were founded to improve services and making them reachable to human being. For instance, to fight the heat, earlier Arab constructors have designed ducts on top of the roof infiltrating the ceiling of the building, allowing continuous air circulations inside particular rooms (Figure.1.).

Figure 1. Ventilation ducts - traditional Arabic architectural signs

Nowadays, buildings are designed to accommodate centralized air conditioning and heating systems. Taking hospitals as an example, operating theaters and recovery rooms are totally dependent on the air supply unit being designed, as it affects the pressure rate and the air curtain created above the patient. The quality of air supplied is very important. Therefore, recently ultraviolet lamps are installed in the air duct to kill germs. Heath and Safety engineers did not exaggerate while adopting the statement "*what is in your duct is what in your lung*".

Duct cleaning is performed manually by accessing pre-identified areas. Some air supply systems can be purged, so the enclosed air inside the ducts is sucked out to filtering station. Intelligent solutions are also present with telerobotics. This approach consists basically of a telescopic snake robot or a mobile robot equipped with spraying guns or

Looping back to old supply ducts systems, the purging solution cannot be used, while manual method consumes lots of time. The telerobotic solution seems to be the optimal choice [5]. Additionally, this approach can be used frequently, essentially for buildings occupied by citizens with special needs (i.e. in-house ventilated patients).

In this paper we discuss the telerobotic solution for duct cleaning for newly built and old structures. In addition, we highlight setup requirements, implementation constraints and possible improvements.

2. Case study

In this paragraph, we present case study on the influence of the air conditioning ducts on hygiene factor inside hospitals. The subject of calibrating, testing, commissioning and inspecting of air ducts and laminar air flows (LAF) in Ultra Clean Ventillation (UCV) OR's is dealt with in different publications including HTM [11], ASHRAE and ISO14644 documentation. In general, the following should be carried out an annual basis for each operating theatre:

a. Particle counting within the area to assure room compliance with ISO5 or ISO7 limits. With this test we used to select 2 significant particle values for compliance, which is normally 0.5μm and 5μm, although the 2015 revision of ISO14644 has removed the 5μm limit from the specification for class 5 [12];
b. Air flow measurement to ensure the correct velocities and air change rates;
c. Filter face scanning involving an upstream injection of smoke / oil drops (DOP) and then systematic scanning of the filter face to measure how much contaminant gets through. This does require an injection point to be designed in upstream of the canopy to the supply ductwork and will shut down the area for the duration of the test.
d. Entrainment test to ensure that particles are not being drawn into the area from outside the air stream (particle counts at perimeters)
e. Microbiological sampling can be used but the above tests are often sufficient.

According to British standard code BS 14065 "Decontamination of linen for health and social care: Guidance for linen processors implementing" used to regulate construction in healthcare premises, soiled and clean areas should be separated physically or functionally. The physical separation consists of building walls between two different areas, while the functional separation undersigns the implementation of treating technologies. For instance, sterilization rooms are both functionally and physically separated. The same applies for the hospital washing room. To avoid cross contamination between different areas, countries has set additional standards to be implemented. For example, In UK, to avoid the influence of the air conditioning, linen has to be washed for three minutes at a temperature of 71℃, or for 10 minutes at 65℃. The same is not applied in Russia and Norway, where the linen is always washed at a temperature of 90℃ and 85℃ respectively. The supplied air does not only affect linen. The total hygiene of the hospital depends on it [1, 10]. The approved norms for hygiene are illustrated in the following diagram (figure.2). Conserving the hygiene factor depends on the Cleaning In Place cycle (CIP), which is divided into four treating procedures: mechanical, chemical, thermal and chronological (refer to figure 3.). The best approach is to increase mechanical procedure with reference to the others. Chemical procedure requires detergents, which may cause side effects. The thermal procedure is directly related to the working atmosphere such as humidity. The air conditioning ducts affects directly the thermal procedure results, as bacteria and germs can survive and multiply easily in such atmosphere.

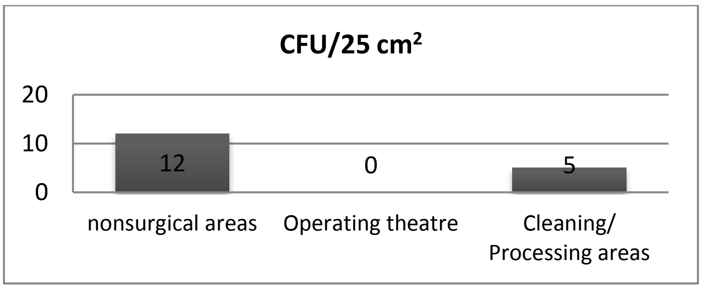

Figure 2. Hygiene factor with reference to room specialty

In addition to side effects, using thermal and chemical procedures are not cost effective and impose indirectly additional financial charges on the habitants or patients.

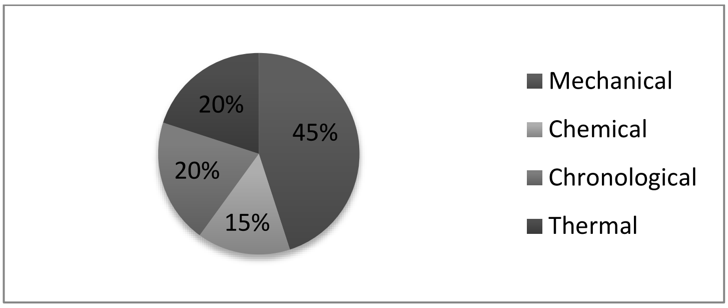

Figure 3. CIP cycle

Ducts are cleaned using ultraviolet lights and manually using vacuum machines but this is not sufficient. As illustrated in figure.4, the ducts can be very dirty between preventive maintenance periods.

Figure 4. Air conditioning duct status A) dirty; B) clean

Subsequently, telerobotic solution can be used to automate long duct cleaning procedures [7,8]. It can be used also to inspect regularly the ducts condition. This solution allows can be integrated with ultraviolet LEDs for old ducts unequipped with special light filters.

3. Telerobotic duct cleaning

From the 2nd paragraph, we can clearly notice that germs and particles affect the airflow and quality. To perform the test (a-e) all equipment to be used should be calibrated annually, which can be an issue for certain countries. In order to avoid such difficulties, hospitals try to select manufacturers with local representation or send their instruments for 2 months just to be calibrated. In the following paragraph, we will describe the robotic concept (Figure.5.), which does not need calibration and it is user-friendly. Hence it does not require special setups and expertise. This can reduce dramatically the maintenance cost and improve the air quality without much hindrance.

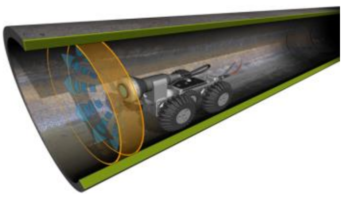

Figure 5. Autonomous/ Telerobotic concept design for air duct cleaning

We will be using articulated robot model since the task is straightforward and does not require sophisticated manipulations. There are several approaches to control the mobile robot. In the literature, most frequently we noticed the implementation of PID regulator due to its simplicity and applicability. On the other hand, with the development in artificial intelligence, adaptive control is used to minimize nonlinear effects such as friction and saturation of the DC motor [4]. Regarding the design of the robotic cleaning procedures, there are different approaches adopting the use of direct dry ice blast cleaning technology as in [2]. Others use intelligent approach to identify the area that needs to be cleaning [3,6].

3.1. *Mobile Robot representation*

The control task consists of tracking the desired metric trajectory. To achieve this goal, it is necessary to model the robotic arm. It is represented as an Elbow manipulator with a base fixation on wheels, body, shoulder, elbow and forearm joints. These mechanisms allow the robot to manipulate three dimensionally to reach difficult corners. Based on Force/Torque relationship, the interaction of the manipulator with the surrounding environment will produce forces and moments on manipulator. We designate F- as the vector of forces and torques identified with the following equation:

$$F = [F_x \quad F_y \quad F_z \quad n_x \quad n_y \quad n_z]^T; \tag{1}$$

where $F_x \quad F_y \quad F_z -$ are the components of the force and $n_x \quad n_y \quad n_z -$ components torques on the grasping tool accordingly. We donate τ for vector of joints torques and δ is the displacement of the end effector caused by the vector F and γ is the corresponding virtual joints displacement. We can write:

$$\delta = J(q) * \gamma; \tag{2}$$

where $J(q) -$ is the Jacobian of the manipulator. The virtual work of the system is given by:

$$\omega = F^T * \gamma - \tau^T * \gamma; \tag{3}$$

By substituting (3) into (2) we obtain:

$$\omega = (F^T * J - \tau^T)\gamma; \tag{4}$$

Since the generalized q is independent, we have the equality

$$\tau = J(q)^T * F; \tag{5}$$

From (5), we obtain the following equality

$$\begin{bmatrix}\tau_1\\ \tau_2\\ \tau_3\\ \tau_4\\ \tau_5\end{bmatrix} = \begin{bmatrix}J_1\\ J_2\\ J_3\\ J_4\\ J_5\end{bmatrix} * \begin{bmatrix}F_x\\ F_y\\ F_z\\ n_x\\ n_y\\ n_z\end{bmatrix}; \tag{6}$$

By obtaining the mathematical model of the controlled manipulator, it is possible to find transfer functions of the compensator. In the following paragraph, we simulate mobile robot with Fuzzy Logic controllers (FLC).

3.2. *FLC Position controller Design*

Positioning of the robot is critical to our case study, as it has to reach difficult corners. In order to design FLC, we should have at least two inputs. We can consider the crisp generated from feedback positioning error and it is deviation in time as inputs for the FLC. The numerical values of the error and its variation in time are obtained while regulating the position using PID controller. The obtained values are segregated as will be represented in form of membership functions MBF. The fuzzy rules are depicted in in figures 6,7 and 8 for "error" input, "deviation" input and "controller output" respectively.

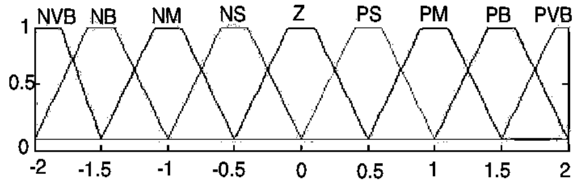

Figure 6. MBF for FLC ERROR input

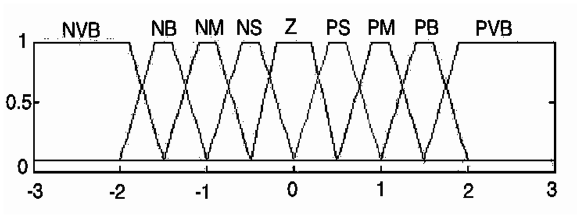

Figure 7. MBF for FLC DEVIATION input

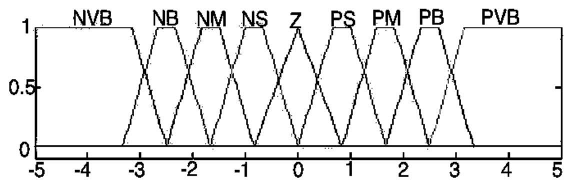

Figure 8. MBF for FLC OUTPUT

In the MBF representation, the following abbreviations are used: NBV- very big negative value, NB- big negative value, NM- medium negative value, NS- small negative value, Z- null value, PS- positive small value, PM- positive medium value, PB- big positive value and PVB- very big positive value. On x-axis, the input/ output variable is represented while on y-axis the degree of membership is identified.

4. Results and discussions

The main control task was to maintain the mobile robot in a certain position in order to achieve collision less maneuverability and safer degree of freedom for the manipulator. This improves the reaching of the spray gun and develops better cleaning results. Figure 9 shows the simulation results for position control.

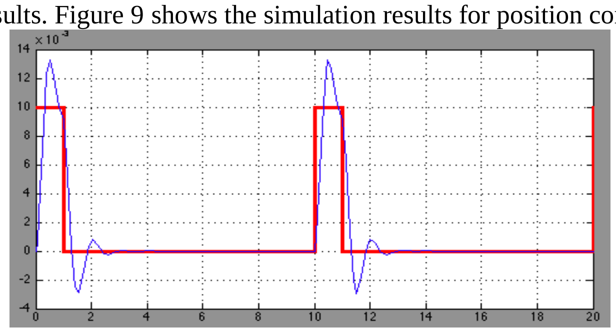

Figure 9. Position control of the mobile robot.

Figure.9 is interpreted as follows: x-axis represents the simulation time (s), y-axis represents the simulation results (position, m). The negative sign indicates the direction. The black pulses designate the control task i.e. the movement coordinates (m); the blue curve is the controlled position of the mobile robot using PID controller (refer to 3.2 Obtaining fuzzy rules and membership functions) while the red curve represents the trajectory of the mobile robot controlled using FLC. The simulation results were obtained based on BioVac Wolverine Robotic systems technical specifications [3], which include the following parameters:

- Robot dimension: 0.4 m x 0.177 m x 0.15 m (High x Length x Width);
- Robot Speed: 1,524 m/s;
- Cable length: 30 meters;
- Weight of the robot: 2.26 Kg.

From the technical specifications, it is assumed that the robot can move into the ducts without hindrance. Albeit the cable length is 30 meters, the diameter of efficiency of the robot can covers large areas up to 2827,43 m^2.
In a related matter, we feel that the need of wireless robotic solution will add value to the mobility factor only as the robot will still be plugged in to water/ detergent supply, which cannot be managed by installing a reservoir on the robot due to payload and dimensions criteria [9].

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Maintenance Strategy of Multi-Equipment Network Systems Based on Topology Vulnerability Analysis

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Abstract

A great variety of mechanical and electrical equipment are distributed along the whole metro line. Equipment maintenance plays a very important role for metro operation safety. But how to ensure the scientificity and rationality of the maintenance plan remains a problem. Maintenance plan is theoretically supported by existing maintenance strategies. This paper proposes a new maintenance strategy which focuses on multi-equipment network systems based on topology vulnerability analysis. BIM is used as an object-oriented database to store the topological relations of network devices, express the equipment maintenance plan, and form a maintenance information storage and data analysis platform. Then vulnerability analysis of the topological structure is carried out. According to the results of the vulnerability analysis, the maintenance plan of the equipment with high degree of topology vulnerability could be optimized. A case study shows that the optimal maintenance plan based on the proposed maintenance strategy can improve the system reliability and reduce cost.

Keywords: equipment maintenance; BIM; complex network; vulnerability

1. Introduction

In the recent years, with the rapid development of urbanization, the subway transportation has been the one of the main tools to solve the urban traffic problems in China. Shanghai and Beijing subway transportation have entered into the network operation phase. However, the largest number of accident precursors (though not the largest number of injuries) during the metro operation is related to different technical failures (Kyriakidis and Hirsch, 2012) [1]. During the lifetime of subway equipment, degrading will lead to its declining performance. In order to protect the subway safety, the maintenance of the subway equipment plays a very important role [2].

Adopt scientific and reasonable equipment maintenance strategy can improve the reliability of equipment, reduce operation and maintenance costs. Hastak and Baim (2001)[3] analyzed the operation cost of various types of urban infrastructure, and points out that the appropriate maintenance strategy has a great influence on the equipment deterioration degree and maintenance management costs. Some maintenance strategies might offer a cheaper and quicker solution to a problem but might lead to accelerated deterioration and need for higher rehabilitation costs (NCHRP 1979b; Manning and NCHRP 1985, 1988; Shanafelt and NCHRP 1985). Farran (2009) [4] used the Markov Decision Process Model to calculate the infrastructure maintenance costs change according to various maintenance strategies. Through analysis, it is found that, when to take scientific and reasonable maintenance strategy, the equipment has more moderate deterioration curve, longer service life and lower life cycle maintenance cost.

Maintenance strategy itself does not contain specific maintenance objects, combined with the specific working environment (for example Metro Equipment), for each device in the system environment pointed out the applicable service behavior and the condition of its application, the purpose of which is to achieve the maintenance strategy is used to solve the criterion, thereby maintenance plan can be directly applied to the specific system maintenance work. Equipment maintenance plan may contain one or more maintenance strategies to achieve different management objectives (Reliability, Cost rate, Availability et al.).

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Subway equipment maintenance program is mainly divided into 3 parts: 1 maintenance and repair list. The included equipment use the preventive maintenance, not listed equipment default to use the corrective maintenance; 2 maintenance cycle. 3 repair content. Such as visual inspection and functional testing.

Maintenance plan is equipment classification in essence, different maintenance strategies are adopted for different equipment: A device with a high degree of importance need to use the preventive maintenance in shorter maintenance cycle and has more comprehensive maintenance content; the maintenance strategies for devices with low degree of importance is opposite.

At present, The problem of making equipment maintenance plan is how to ensure the rationality of maintenance strategy, that is to say, how to divide the equipment importance more scientifically, to realize the high reliability and low cost.

However, the existing maintenance plan only consider the performance of a single device, and consider the whole system, the subway system can be seen as a complex network system. With the vulnerability of network structure, the vulnerability of each device in the network of the whole equipment will affect its important degree. Therefore, it is necessary to put forward a kind of maintenance strategy based on the vulnerability of the network, more scientific classification of equipment importance, to optimize the equipment maintenance plan.

This paper apply IFC Standard as an object-oriented database, storage the topological relations of network devices and express the equipment maintenance strategy, form a maintenance information storage and data analysis platform, then analyzed the topological structure vulnerability. According to the results of the analysis of the vulnerability, optimize the maintenance strategy of the equipment with high degree of vulnerability.

2. Methodology

2.1. *Complex network theory*

The subway equipment system can be seen as a complex network system which composed of the equipment as the edge, the equipment as the node. The external emergencies such as natural disasters, terrorist attacks and artificial destruction, staff operational errors, equipment failure, may lead to local failure of the line network, thus affecting the normal function of the line of the other part of the equipment, failure will spread to the entire network, leading to more damage, resulting in network capacity and efficiency is reduced obviously. Therefore, subway equipment network has network structural vulnerability, namely in the topology of the network any functional unit reduce or failure, its connected nodes and connections as carrier of communication failure, the failure influence will extend to the local and even the entire network. When due to disturbances or impact a certain point of the subway equipment network failures, that will have a cascading effect, impact on the connectivity of the point line, and the key node failure and even cause network paralysis. Wang Z [5] reviews the methodologies used in vulnerability analysis of transportation networks and particularly focuses on the application of complex network theory.

2.2. *BIM and IFC*

BIM (Building Information Modeling) technology has attracted more and more attention in AEC/FM (Architecture, Engineering and Construction/ Facility Management) field because it introduces a revolutionary technology comparable to CAD that emerged about two decades ago. BIM is an object-oriented database: Faraj et al. developed an IFC Web-based collaborative construction computer environment called WISPER (Web-based IFC Shared Project Environment), which built an IFC-based object-oriented database to help users realize the network integration and sharing of the design, budget, schedule and other information in construction projects[6]. To help facility managers better manage lifecycle information pertinent to managing the facility and responding to facility related patient safety events, an object oriented product model is proposed in the context of developing a healthcare facility information management framework [7]. Thus, this paper apply BIM to storage the topological relations of network devices which is needed in complex network theory and express the equipment maintenance strategy.

3. Basic theory of complex network

Complex network is a network model with a large number of nodes and complex connection topology. In 1998, Watts et al. [8] proposed the concept of the famous small world network. In 1999, Barabbsi et al. [9] proposed the concept of scale free network. Currently, many systems can be viewed as complex networks, such as the Internet, social networks, and rail networks. Complex network theory is used to study the common characteristics of all kinds of complex networks and to deal with them. There are many statistical characteristics to describe the complex network structure, including the shortest path, clustering coefficient, betweenness centrality, average degree and average distance, connectivity distribution, correlation coefficient, of which there are three most basic and important statistical characteristics, namely degree, clustering coefficient and average path length, Here is a brief description of them.

3.1. *Degree and degree distribution of nodes*

The degree i of the node k represents the total number of edges connected to the node i. The average value of the degree k of all nodes in the network is defined as the average degree of the network, which is defined as <k>. Distribution function p(k) express the network node degree distribution, its meaning is the probability of randomly choosing a nodes of k edges, is also equal to the ratio of k degree nodes and the total number of nodes in the network.

3.2. *Network path length*

The shortest path between nodes i and j in the network is defined as the minimum number of sites connected to the two nodes. The average path length L of the network is defined as the value of the average distance between any two nodes, namely

$$L = \frac{1}{\frac{1}{2}N(N+1)} \sum_{i \geq j} d_{ij} \qquad (1)$$

In the formula: N is the number of nodes in the network; d_{ij} is the shortest path between the nodes i and j. Here is defined as the minimum number of the site to connect the two nodes.

3.3. *Vulnerability of network structure*

Vulnerability is a sensitive factor that indicate the decrease of service level due to the impact of events. The vulnerability of equipment system can be defined as the probability of the equipment system global efficiency under the attack of different equipment. There are a number of indicators to the network vulnerability, including the relative size of the maximal connected sub graph [10], and network efficiency [11]. The author describes the vulnerability by the equipment network efficiency.

Network efficiency E is used to measure the efficiency of node exchange information in the network. Before G is defined the average network efficiency, the shortest path between any two points $\{d_{ij}\}$ is needed. Set e_{ij} as the efficiency between the vertices i and j which is the reciprocal of the shortest path: $e_{ij} = 1/d_{ij}$, when there are no edge connection between i and j, $d_{ij} = +\infty$, $e_{ij} = 0$, so the average network efficiency of G can be defined as:

$$E(G) = \frac{\Sigma_{i \neq j \in G} e_{ij}}{N(N-1)} = \frac{1}{N(N-1)} \sum_{i \neq j \in G} \frac{1}{d_{ij}} \qquad (2)$$

When the value of E is very large, the network efficiency is very high and the connectivity is very good. When node i was attacked, the network is destroyed, network efficiency is also affected, different node failure causes different network efficiency change, so the vulnerability of node i is defined as:

$$\xi_V = \left[E(G_i') / E(G) \right]^{-1} \qquad (3)$$

In the formula: G_i' indicates that the node i in G has been attacked and failed, $E(G_i')$ shows the average network efficiency after node i failure, $E(G_i')/E(G)$ is the percentage of the network efficiency and the original efficiency after the failure. Vulnerability ξ_V is expressed as the reciprocal of the efficiency, the greater ξ_V is, the higher vulnerability of the node is, and the network failure caused by node failure is more serious [12]. The biggest vulnerability node is the key nodes that has the highest influence for the overall network efficiency. After defining the network efficiency E, we can determine the key nodes in the network.

4. Case study

4.1. *Network structure of a subway equipment network*

Taking a subway smoke exhaust equipment network as the object of study, analyzing the vulnerability of the topology structure in depth.

First, we extend the IFC framework to apply the attribute set for the vulnerability analysis of metro equipment. Because of the need to establish the complex network model, we need to obtain the relationship between the upstream and downstream of the equipment, and the upstream and downstream of each device will be connected to form a complete network of equipment. Therefore, four attributes of the entity object will extend for APYF, AFHF, Air valve and so on devices, as shown in Figure 1: Ifcfacilityno (the number of equipment in calculation), Ifcfacilitycode (the equipment code in metro facility network), Ifcupstreamfacilitycode (Coding of upstream equipment), Ifcdownstreamfacilitycode (Coding of downstream equipment).

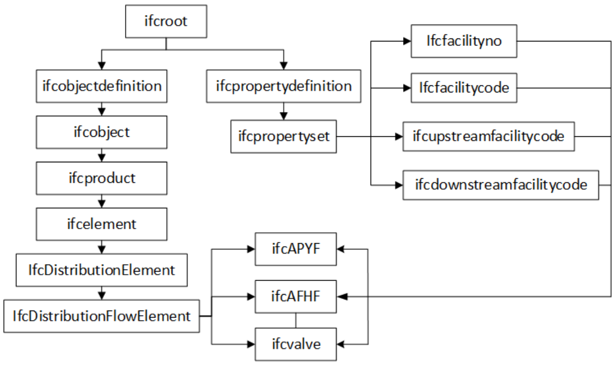

Figure 1 Kernel of the maintenance schema in Express-G format

Facility No.	Facility Code	Facility Type	Upstream facility	Downstream equipment
1	W-E-F03-01-ER04-01-KT_F-4101	Static pressure tank		W-E-F03-01-AR02-01-KT_F-1509
2	W-E-F03-01-AR02-01-KT_F-1509	APYF	W-E-F03-01-ER04-01-KT_F-4101	W-E-F03-01-AR02-01-KT_F-1508
3	W-E-F03-01-AR02-01-KT_F-1508	DT-Electric regulating air valve	W-E-F03-01-AR02-01-KT_F-1509	W-E-F03-01-ER04-01-KT_F-0803
4	W-E-F03-01-ER04-01-KT_F-0803	PY-AS(1)-01	W-E-F03-01-AR02-01-KT_F-1508	W-E-F03-01-AR02-01-KT_F-1528
5	W-E-F03-01-AR02-01-KT_F-1528	APYF	W-E-F03-01-ER04-01-KT_F-0803	W-E-F03-01-ER03-01-KT_F-1501
6	W-E-F03-01-ER03-01-KT_F-1501	Muffler	W-E-F03-01-AR02-01-KT_F-1528	W-E-F03-01-ER03-01-KT_F-1502
7	W-E-F03-01-ER03-01-KT_F-1502	Muffler	W-E-F03-01-ER03-01-KT_F-1501	W-E-F03-01-AR02-01-KT_F-1526
8	W-E-F03-01-AR02-01-KT_F-1526	APYF	W-E-F03-01-ER03-01-KT_F-1502	W-B-F03-01-PS01-01-KT_F-5701/W-B-F03-01-PS01-01-KT_F-5801/W-B-F03-01-PS01-01-KT_F-5901/W-B-F03-01-PS01-01-KT_F-6001/W-B-F03-01-PS01-01-KT_F-5702/W-B-F03-01-PS01-01-KT_F-6101
9	W-B-F03-01-PS01-01-KT_F-5701	Shutter air outlet	W-E-F03-01-AR02-01-KT_F-1526	
10	W-B-F03-01-PS01-01-KT_F-5801	Shutter air outlet	W-E-F03-01-AR02-01-KT_F-1526	
11	W-B-F03-01-PS01-01-KT_F-5901	Shutter air outlet	W-E-F03-01-AR02-01-KT_F-1526	
12	W-B-F03-01-PS01-01-KT_F-6001	Shutter air outlet	W-E-F03-01-AR02-01-KT_F-1526	
13	W-B-F03-01-PS01-01-KT_F-5702	Shutter air outlet	W-E-F03-01-AR02-01-KT_F-1526	
14	W-B-F03-01-PS01-01-KT_F-6101	Shutter air outlet	W-E-F03-01-AR02-01-KT_F-1526	
17	W-E-F03-01-AR02-01-KT_F-1503	APYF		W-E-F03-01-AR02-01-KT_F-1520
18	W-E-F03-01-AR02-01-KT_F-1520	APYF	W-E-F03-01-AR02-01-KT_F-1503	W-E-F03-01-ER04-02-KT_F-4102
19	W-E-F03-01-ER04-02-KT_F-4102	Static pressure tank	W-E-F03-01-AR02-01-KT_F-1520	W-E-F03-01-ER04-02-KT_F-0801

Table 1 the relationship between the upper and lower reaches of a subway exhaust equipment

As shown in the table1, the subway smoke exhaust equipment including muffler, static pressure tank, APYF, AFHF, shutter air outlet, DT-Electric regulating air and so on, totally 99 equipment nodes. Each device has a special code, the code is unique in the entire subway network equipment. Table1 lists the relationship between the upstream and downstream smoke exhaust equipment between all nodes, shows the topology relationship of all equipment in the smoke exhaust system.

4.2. *Vulnerability analysis of Metro Equipment Network*

Using Pajek software establish a directed graph network model of the subway smoke exhaust equipment, and then use the formula (3) to calculate the structure vulnerability of the equipment network.

Calculate the smoke exhaust equipment network number of nodes and the number of edges, average degree, average path length and clustering coefficient. The result is shown in Table2.

Table 2 Characteristic index values of smoke exhaust equipment network

Characteristic index	Value
Number of nodes	99
Number of edges	195
In-degree / Out-Degree / Total-Degree	0.95/0.95/1.90
Average path length	4.46

Table5.2 shows the at present the smoke exhaust system totally has 99 equipment, 195 connected edge, each equipment average directly connect with 1.90 equipment, that indicates the lines cross between less each equipment is not much, and average path length is 446, it has few average path length. According to the complex network theory, the smoke exhaust equipment network has the characteristics of random network.

99 nodes in the network of smoke exhaust equipment were deliberately attacked, and the efficiency of the network was calculated by the formula (2). After calculation, the network efficiency of smoke exhaust equipment network $E(G)$ is 0.0234. After calculation and analysis of the formula (3), shows that the No.9, No.18, No.35, No.46, No.50 nodes have a greater impact on the network efficiency, and the vulnerability coefficient is higher, as shown in Table3.

Table 3 Vulnerability correction factor of partial nodes

Facility No.	Facility Code	Facility Type	$E(G_i')$	Network efficiency change rate/%	ξ_V
9	W-E-F03-01-AR02-01-KT_F-1503	APYF	0.0197	12.34	1.12
18	W-E-F03-01-AR02-01-KT_F-1525	AFHF	0.0205	6.87	1.07
35	W-B-F03-04-ER02-01-KT_F-2087	AFHF	0.0186	16.21	1.16
46	W-B-F03-04-ER02-01-KT_F-2040	AFHF	0.0183	14.13	1.14
50	W-B-F03-04-ER02-01-KT_F-2032	DT-Electric regulating air valve	0.0207	7.92	1.08

4.3. *Maintenance plan optimization*

The result shows that the deliberate attack on a subway exhaust equipment network efficiency is big, the No. 9, No. 35, No.46, are the key nodes with highest vulnerable, should take more stringent equipment maintenance strategy to protect the performance of these devices.

The existing maintenance plan is: do visual inspection for the valves within 6 months. But the No. 9, No. 35, No.46, are the key nodes with highest vulnerable, and higher important degree. We need to optimize their maintenance plan, since the existing original maintenance plan is preventive maintenance, but the maintenance cycle is too long, the maintenance content is too simple. So modify it to do visual inspection and performance testing within 1 month.

5. Conclusion

The author extended the existing IFC standards, applied BIM as an object-oriented database, storage the topological relations of network devices and express the equipment maintenance strategy. And put forward the quantitative analysis method for structure vulnerability of the network, based on complex network theory, from the node degree, the average path length of metro equipment network topology analysis, and proposed the network node vulnerability calculation method based on the network efficiency. The maintenance plan optimization according to the method proposed in this paper, can improve the reliability of the equipment system.

Using complex network theory to analyze the vulnerability of metro equipment network, without taking into account the probability of failure of the station. In the face of natural disasters, the probability of failure of different sites is different, and the vulnerability of the network of metro equipment can be regarded as the integration of the probability of failure and the degree of impact. Subway equipment network vulnerability analysis can take this factor into account, can enrich the subway equipment network vulnerability analysis theory, and the practice has a more important reference.

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A Cloud-Based Mobile System to Manage Lessons-Learned in Construction Projects

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Abstract

Knowledge and experience are vital assets within the construction industry. Nevertheless, small and medium construction companies still have problems to transfer the knowledge acquired in their projects to the rest of the organization. Lessons-learned are elements of knowledge management that could help companies to improve this process, and therefore, their global performance. This research presents a cloud-based mobile shared workspace to support knowledge management in construction. The article presents the original ystem and the modifications made to it based on an initial evaluation by construction professionals. The main upgrades were to include a notification system, letting user's know when an action is required from them, and to improve the synchronization process for a better offline experience on site. The evaluators considered these were essentials features to be able to use the system on site. The 2.0 version of the system was validated with construction experts. The article concludes that one of the most relevant features of the system is its capacity to save information on site without an internet connection for later synchronization. Also, the proposed cloud-based shared workspace is a feasible option to improve knowledge management in small and medium Chilean construction companies, mainly because of mobility, usability and investment-related factors.

Keywords: cloud computing; knowledge management; mobile information systems; shared workspaces

1. Introduction

Construction companies are project based organizations characterized by uniqueness, uncertainty and complexity, which makes them different from other business organizations [1]. Thus, it is difficult to manage the knowledge they generate during the progress to deliver a custom-built facility [2]. In fact, many project based organizations constantly fail to learn from their own experience, as shown by their tendency to 'reinvent the wheel', repeating mistakes and failing to transfer lessons from one project to another [3]. These difficulties arise due to the unique and discontinuous nature of project-based work, which creates intra-firm boundaries that hinder the transfer and use of valuable knowledge gained within particular projects to subsequent projects and/or the organization as a whole [4].

In this regard, efficient Knowledge Management (KM) would allow construction companies to transfer knowledge across their various projects, to create synergies inside the organization, to learn from the mistakes and successes of others, and to receive benefits in terms of productivity and performance [5]. Despite this, construction organizations have historically failed at effectively transferring project information and have not yet developed a learning culture that takes into account both technology and people [6]. This is a complex situation, as transferring learning to future projects allows staff to use existing knowledge to solve problems, instead of having to generate new knowledge which generally requires more time [5]. This also could hinder a companies' performance, as effective KM is believed to be one of the performance enhancers for organizations wanting to remain successful in the construction industry [7].

There are different approaches to conduct KM, such as self-service, communities of practice, transfer of best practices and lessons learned [8]. Lessons learned (LL) are elements of both organizational learning and KM [9] as they capture knowledge from projects, events, or other work to apply in similar situations [8]. Typically, LL from different construction projects are not systematically integrated into a construction firm's memory [5]. In fact, the benefits of learning are still not realized, despite the efforts of some construction companies [10]. There is also the need to maximize opportunities for people to meet and make an efficient use of information technologies (IT) to find information and knowledge [11]. Because of that, this research explores how to use some trending IT, such as mobile cloud computing to the collaborative KM process in medium-sized Chilean construction companies. Specifically, this article presents the first version of a cloud-based mobile system to manage LL in construction companies, developed under the Lean Startup methodology. It also shows the improvements made to the first version, following the feedback received from construction professionals and experts.

2. Review of literature

Companies have come to understand knowledge as a resource and a vital asset to carry out their activities. They have implemented various ways of capturing, storing, transferring and reusing it [5]. For example, large companies as Fluor have KM programs including communities of practice, expertise locator system, mentoring, people developments programs, online collaboration, document management spaces, and process improvements methodologies to capture and transfer critical knowledge [8]. Despite these successful experiences, several construction companies still have problems regarding their KM, especially about extracting, distributing and applying knowledge across both cultural and structural boundaries, given its condition of project based industry [12].

An interesting approach to KM is the use of LL. Lessons learned are knowledge gained from experience, successful or otherwise, for the purpose of improving future performance [13]. A LL process include mainly three steps: identification (capture), dissemination (transferring) and application (implementation). The last one appears to be the most difficult to operationalize [14]. A survey made to major construction contractors in the UK [10] helps to understand current practices of LL. Its findings include: (1) The most commonly used practices for LL activities include both explicit and tacit methods such as post project reviews (68%), company intranet/extranet (64%), and face-to-face meetings (62%); (2) the most informative practices include communities of practice (56%), brainstorming sessions (54%), and knowledge repositories (53%), followed by post project reviews (52%) and face-to-face meetings (52%) and to a lesser extent technical forums (42%); and (3) Face-to-face meeting and post project reviews were commonly used and most informative. Regarding the adoption of corporate LL processes by site teams, Carrillo et al [15] identified some challenges that need to be addressed, such as (1) lack of communication and transparency between site teams and head office teams; (2) strong emphasis on people-to-people dissemination even though they have received tools from the corporate office which they consider useful ; (3) a culture of encouraging the collection and dissemination of lessons needs to be addressed; and (4) site teams do not properly recognize the value in collating lessons and therefore excuse themselves by saying they do not have enough time.

It is important to consider that most of the studies regarding LL in the construction industry have been conducted in developed countries. Thus, these studies have focused on large and/or international construction companies or have assumed that LL are an issue that a large number of companies already have implemented. Therefore, the implementation and adoption of LL systems in small and medium size construction companies, especially in developing countries, have not been adequately studied in the past. This occurs even though construction industry comprises primarily small and medium enterprises (SME) [16], with less opportunities to implement new technologies.

Previous research [17,18] has shown that, within small and medium size companies, knowledge is generally kept in people's minds and not documented for the benefit of the organization, despite the fact that they acknowledge the need for LL in the design and execution of future projects in order to reduce or prevent errors. Regarding this, some problems faced by SMEs in the construction industry include [18] the following:

- The lack of organizational procedures to manage knowledge. Construction professionals have indicated that they do not store knowledge because it is not clearly defined what information or knowledge they need to store, what format to store it in, or where to store it.
- Communication and cooperation between professionals of the same company is difficult and slow, given the geographical dispersion of projects.
- A major limitation to capture and store knowledge is the lack of time during the execution of projects. This has an impact in the communication process project teams, experts, and the central office.

3. Methodology

This research was conducted using the Lean Startup methodology because (1) it was necessary to understand the uniqueness of the construction SME's requirements and (2) the main goal of this research is to develop a functional product. Lean Startup is an approach that seeks to eliminate the waste of time and resources spent on the effort of trying to understand what customers really want [19]. The core of the Lean Startup model is the Build-Measure-Learn feedback loop. This process allows to turn ideas into products, measure how customers respond, and learn whether to pivot or persevere [20]. This research has completed the Build-Measure-Learn cycle three times so far.

The goal of the first cycle was to create a valuable system proposal. During the initial Learning phase, we identified deficiencies in the KM and LL processes, through a literature review and semi-structured interviews with 16 construction professionals from 3 different construction companies. During the Building phase, initial mockups were made. Later, the Measurement phase consisted in new semi-structured interviews with 5 construction experts within the companies.

The second cycle focused on building a first version of the system, to test the proposal with on-site professionals. In order to do so, during the Building phase the main functionalities were implemented in a cloud service. During the Measurement phase we worked in detail with one company from the previous cycle. A team of on-site professionals used the prototype to register and access LL from an on-going project and then participated in a focus group. Also, periodic interviews with the COO (Chief Operating Officer) and Innovation Chief continued, in order to consider both the operational and managerial vision. Finally, during the Learning phase, the results and comments from the focus group and the interviews with the managers were analyzed.

The goal of the third cycle was to improve the first prototype, after it proved to be useful on measurement phase of the second cycle. The Building phase focused on the development of the version 2.0 of the system, based on previous cycle's feedback, including a cross-platform mobile application and the improvement of the existing cloud service. During the Measurement phase, expert construction professionals were consulted and interviewed to receive feedback regarding the system's performance. Also, currently there is an on-going test on site in the construction company that participated in the previous cycles.

4. System development and improvement

4.1. *General description*

The proposed LL system is a cloud-based mobile shared workspace. Its main features are grouped in two modules fostering both explicit and tacit knowledge management: (1) an organizational database of lessons-learned, and (2) an organizational microblog. The lessons-learned database allows the storing, reusing and transferring of knowledge created in the design and construction phases of a project, avoiding the re-occurrence of mistakes. Regarding the organizational microblog, it is design to allow a more fluid contact among professionals, fostering tacit knowledge transfer, as interactive IT tools are often preferred over face-to face interaction, between both co-located and distributed workers since they are non-intrusive and commonly support multitasking [21].

The cloud-based mobile shared workspace's architecture considers three main components: (1) a Cloud-based service platform, (2) a Web-based software solution, (3) a Mobile software solution. Both web and mobile applications allow access to system's functionalities, by consuming the services exposed by the cloud service. The web application's main goal is to allow access to all shared workspace's functionalities, including usage of the microblog, creation, consultation and evaluation of lessons-learned, besides system management options. On the other hand, the mobile application is under development for Android, iOS and Windows Phone devices, using Xamarin.Forms, a C# multiplatform framework which allows to easily communicate with the C# built core. Main goals for the mobile application are to allow quick and comfortable field data collection and to allow timely access to LL already published in the system, supporting decision making. This application considers the same functionalities as the web application, except for system management options, and consumes a specialized cloud service for mobile devices. Finally, the worker role in the cloud provides the common ground for all client applications and it is responsible for handling business logic. It is implemented using Entity Framework 6 and centralizes access to the LL system's database and storage.

This system recognizes four types of users: System Manager, Lessons Creator, Approver, and Consultant. These users perform four main tasks regarding the LL stored in the system:

- Creation: The system (web or mobile) displays a LL form to be completed with relevant content. The lesson content was defined with the construction companies that work on the case study [18], and then refined with the company that decided to implement the system.
- Approval: To ensure accountability and credibility to the lessons included on the database, each new lesson has to be approved by one or more Approvers. They can ask the authors to make improvements to their LL.
- Search: It is possible to search lessons through a quick search feature, which allows searching by keywords; and through an advanced search, which allows searching using filters such as lessons title, author, approvers and project's name, disciplines, source of the lessons, and lessons' tags.
- Evaluation: Users give explicit or implicit feedback about LL's content and relevance, regarding their experience using them. This information is input for the future development of a recommendation system.

4.2. *Initial evaluation of the system*

The pilot implementation was conducted in project involving the work of finishing the common spaces (2,400 m2) of a mayor office building. The company that owned the project has more than 20 years of experience in the area. The team that participated on the system validation included 7 construction professionals. The evaluation conducted at the end of the pilot implementation had three parts: (1) an overall assessment of the system, using elements defined in ISO/IEC 25010: 2011 quality software standard [22], (2) an assessment of usability, according to the System Usability Scale (SUS) [23], and (3) open questions to identify perceptions and opinions of users.

The result of the evaluation (scores and comments) shows a positive reception of the system's proposal, as all users agreed that system can be considered as a tool that contributes to the improvement of the construction management process on site. Not only were the system's features well evaluated, but also its usability. The average SUS score was 80.42, and a SUS score among 80 and 90 is considered excellent [24]. Nevertheless, the system could be improve. Regarding the limitations that could hinder the proper use of the system inside the company, most concerns related to technical aspects of the system, such as the quick access to knowledge through the database search, and the use of an unstable internet connection on site. The items that presented the lowest scores were associated with the response speed time of the system and the speed to access to the information and knowledge provided by the system, followed by the adaptation of the system to the use in everyday work.

Here we can identify two main concerns. Firstly, how the technical features of the system could cope with the lack of time in construction projects, especially regarding the quick access to knowledge through the database search, using an unstable internet connection on site. Secondly, how the particularities of the construction industry, such as its traditionalism, lack of IT implementation, lack of training of the workforce, geographical location, work on site and not at the main office, among others, could affect the use of the system in everyday work. About modifications that can be done to the system to improve its usability for every day work, the interviewees pointed, among other things that it could be good to (1) have graphical environment improvements (2) get e-mail notifications for approvals, rejections or other messages, (3) improve search feature, (4) foster the culture and openness to innovation and (5) improve offline functionalities. Company managers and interviewees agreed on these points.

4.3. *Improvements made to the system*

Following the evaluation's results and the periodic interviews with the company's Project Management Office and Innovation Office, authors decided to make lessons' approval and evaluation more flexible and less intrusive, in order to encourage more users to enter information to the LL system more often. Another decision made after the evaluation was to implement push notifications. This feature will draw more attention to the system while facilitating and guiding access to relevant information.

To encourage users to participate, the lessons will now require only one supervisor's approval before it is published. This way, the results of an author's work will be visible more quickly. The second approval will be optional, as it was designed for higher level experts, whom may not have enough time to review all the LL they will receive. Thus, there will be balance between ensuring the quality and achieve a smaller amount of bureaucracy before a lesson is published. Also, regarding the LL evaluation and feedback process, after the system's evaluation the problem of discouraging bad-evaluated lesson's authors became notorious. To avoid this, the five star ranking option was replaced with implicit feedback. The option to comment remained, as it is an opportunity to have constructive feedback to help improve authors' future interventions. Table 1 summarizes the main differences between the first and second versions.

Table 1. Main improvements from version 1.0 to version 2.0

Feature	Version 1.0	Version 2.0
Approval	Requires two users to approve the lesson before its published	Requires only the first user to approve before it is published. The second approval it is optional, but desirable.
Evaluation	Allows users to post comments and to rate lessons with 1 to 5 "stars" (the more stars, the better)	Allows users to post comments. The system measures how much people reads the lesson.
Notifications	Non-existent	The system sends push notifications to mobile devices when an action is required from the user at some stage of the approval process and when the lesson created by the user is finally published.
Offline use	Work in progress can be saved locally. Synchronization with remote server is manual.	Work in progress can be saved locally if there is no internet connection (mobile application). Synchronization is automatic.

This new version was evaluated by 7 construction experts, following the same three-part questionnaire used to evaluate the first version. Improvements were well received. Experts said the changes made to the system were consistent with work in the industry. This time, the average SUS score for the system was 84. Work under unstable internet connection is still a major concern. The most frequent comment in both evaluations was the importance of being able to work without Internet connection. In this case, the experts noted that the system could not be used at all without this feature.

5. Conclusions

The results of this ongoing research show that the issues of how to manage knowledge in construction companies are not totally resolved, especially in SME from developing countries. To offer a solution to these problems we developed a cloud-based mobile shared workspace.

Construction companies has been slow in the adoption of IT. One of the many reasons for this situation is the fact that many of the systems currently offered in the market were developed without addressing the real needs of construction companies regarding their project's work conditions and culture. Therefore, one way to improve the use of IT in these companies, especially in SME, is through the use of more collaborative methodologies such as lean startup. A work methodology like this one allows for a direct involvement of the final user in the system development, allowing the creation of systems that are really useful in everyday work. For example, our results show that one of the main concerns of construction professionals was the capacity of the system to save information on site without internet connection. Requirements like this one are not the main focus of previous academic researches, and are often overlooked.

The version 2.0 of the system includes new features according to construction professionals' feedback. These improvements were well received by construction experts that evaluated them later, leading us to believe that the application of methodologies of collaborative work could increase the chance of success of IT implementations on site in construction projects. Finally, the cloud-based mobile shared workspace was considered a very useful tool to manage LL in project. The next step of this research will include the use of the new version system in a construction project.

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Hi-dependable Wireless Monitoring Solution for Freight Management in Underground Work Sites

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Abstract

Many of the measures taken in underground work sites are collected manually and with the constant intervention of operators and maintenance staff. This may lead, in some cases, to errors and/or planning delays and as a result, to an increase of the final work costs. In the case of railway equipment inside tunnels, mechanisms for monitoring and management are scarce and usually insufficient for proper operation and they become critical during indoors construction work.
Therefore, it is necessary the development of a system able to immediately detect any problem in the train or in the tunnel infrastructure, react quickly and mitigate effectively the possible consequences.
In this context, the European project DEWI (Dependable Embedded Wireless Infrastructure) provides key solutions for wireless seamless connectivity and interoperability in rail domain, among others: automotive, aeronautics and buildings. A "sensor & communication bubble" using wireless technology enables less expensive and more flexible maintenance and re-configuration.
ACCIONA Infraestructuras is implementing a prototype capable of managing freight trains at construction work sites, able to prevent disasters and accidents at building (or refurbishment) stage in large underground areas by considering everyday physical parameters of the trains and their loads. This will significantly contribute to decrease project costs, operation and maintenance of the equipment and facilities, as well as to the optimization of the operation of the rail machinery in terms of time. In this paper a first approach to solve the mentioned issues is presented.
Furthermore, the proposed solution shall be able to reduce the effort and time required for integrating WSN solutions and, railway safety-related and multipurpose systems, and to reduce maintenance costs of on-board WSN services.
DEWI project has been financed by the ARTEMIS Joint Undertaking and the respective National Public Authorities under the ARTEMIS Call 2013.

Keywords: Efficient resource and cost control; Rail; Safety and Security; Underground work sites; Wireless sensor networks.

1. Introduction

The building or remodelling of large underground areas, such as tunnels, implies very complex projects where some very specific needs appear.

Historically, tunnels have been considered dangerous places where fatal accidents during construction works were inevitable. Not any more: nowadays, tunnel safety is an essential aspect all over the European countries, and particularly in Spain.

Site management during the construction phase is also of essence: effective management of both resources within the tunnel (workers, raw materials, tools, etc.) and the machinery involved is required to accomplish the ultimate goal of improving the effectiveness and efficiency of the construction site.

Most of the resources are moved by trains due to their ability to transport huge amounts of materials consuming less time and effort. Many measurements taken in underground work sites are collected manually by operators and maintenance staff. This may lead, in some cases, to errors and planning delays, increasing final work costs.

In the case of railway equipment inside tunnels, mechanisms for monitoring and management are scarce and usually insufficient for proper operation and they become critical during indoors construction work.

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In this context, the European project DEWI (Dependable Embedded Wireless Infrastructure) provides key solutions for wireless seamless connectivity and interoperability in the rail domain.
Therefore, the development of a quick-response system is necessary. Said system should be able to immediately detect any problems, being them in the train or in the tunnel infrastructure, and effectively mitigate possible consequences.

ACCIONA Infraestructuras has designed a prototype capable of managing freight trains at construction work sites, able to prevent disasters and accidents at building (or refurbishment) stage in large underground areas by considering everyday physical parameters of the trains and their loads.

Figure 1 ACCIONA platform wagons (source ACCIONA)

2. DEWI, an overview

DEWI (Dependable Embedded Wireless Infrastructure) [1] is one of the largest funded European Research & Development (R&D) [2] initiatives with 57 renowned industrial and research partners from 11 European countries. DEWI focusses on wireless sensor networks and wireless communication to provide new applications for citizens and professional users. It envisions to significantly foster Europe's leading position in embedded wireless systems and smart (mobile) environments such as on- and off-road vehicles, railway cars, airplanes and buildings.

For this, DEWI has introduced the concept of a "Sensor & Communication Bubble" – the so-called DEWI Bubble – featuring [1]:

- Locally confined wireless internal and external access
- Secure and dependable wireless communication and safe operation
- Fast, easy and stress-free access to smart environments
- Flexible self-organization, re-configuration, resiliency and adaptability
- Open solutions and standards for cross-domain reusability and interoperability

2.1. *DEWI Rail Industrial Domain*

The DEWI Rail Domain proposes novel solutions to optimize freight management. A Wireless Sensor Network (WSN) [3] will be deployed along the different wagons and locomotives of a train which will send the data about freight status, train composition and/or train integrity to a gateway. This gateway is responsible to store and manage the collected data, sending it to the system or person requiring information, such as the driver or external services. Wireless technologies in the rail domain may ease maintenance, reduce installation costs, and increase the safety level for some applications or systems.

In actual freight management, the link between wagons, the identification of their physical characteristics and parameters and the control of the status of the freight travelling inside the train composition are mainly mechanical processes. A wireless solution provides easier, quicker and dynamic identification and monitoring of the freight travelling inside the train composition, avoiding complex and expensive installations. This is especially interesting for trains transporting hazardous materials where early status detection is very important in order to run safely.

3. Monitoring solution for freight management in underground work sites

ACCIONA solution describes [4] how to deploy a structural wireless monitoring system capable of measuring the most relevant parameters and physical variables involved in the train mechanical structures and their freight.

Freight trains in charge of transporting the material for construction works should be continuously monitored by identifying their load, the nature of these loads, their weight and physical conditions, in order to achieve the work optimization of the rail machinery in terms of time, project, operation and maintenance costs of the equipment and facilities.

The freight train travels on the railway route inside the tunnel, along with other trains and other construction machinery during the construction works. The train composition is changed outside the tunnel depending on the needs of running works inside. In fact, the cargo is also selected and loaded on their particular wagons, depending on their characteristics, nature, form and weight.

As a result of all of this, each type of wagon should be monitored in a different way with specific sensors adapted to the specific cargo of the wagon.

Table 1 Underground worksites specialized wagons

Wagon	Description
Locomotive Cab	Locomotive Cab is the part of the train where a driver or engineer is located and where you can find the controls necessary for the locomotive's rail operation. Inside this wagon it is necessary the installation of comfort and air quality sensors, in order to improve the wellness and security of the driver. In the same way, air quality sensors have been deployed to exactly know the CO2. Good air quality in tunnels is vital, it affects staff health and therefore, badly managed air quality can have economic and legal implications.
Staff Wagon	Staff Wagon is a wagon in charge of transporting staff along the tunnel and of interchanging workers at the end of each work shift. The same sensors with the same objective as in locomotive cab should be deployed: THL and CO2 sensor.
Bulk Container	These wagons transport material such as granular and powdered diverse merchandise, cement or big blocks of rocks. They are made of steel. Material temperature sensor node is needed for monitoring the bulk cargo status during the transporting process. As the information will be sent and stored, the operators can take care of the real temperature of the material. Then they will able to detect any dangerous reading of temperature that could lead to an accident or in a fault or deformation of the transported material.
Platform Wagon	They are used to load large goods), such as machinery, cables, steel coils and metal vehicles action, among others. Load Detection Sensors could be used to monitor and control the right position of the cargo on the wagon and alert us about falling objects or materials which could damage other transported material or harm the workers. Distance Sensor has the same objective than the load detection sensor. The worker will choose between one or the other depending on the shape and size of the transported material.
Gas or Liquid Wagon	A tank car is a type of railroad car or rolling stock designed to transport liquid and gaseous commodities (such as fuels, oils, hydrogen, natural gas, etc.) that can be necessary for the proper operation of works inside the tunnel. During the construction works, the machinery involved in the daily operations needs to be filled up with fuel or gas; substances of this nature are very flammable and harmful. A thermocouple could be used to monitor the temperature of the gas or liquid wagon during the journey, detecting any threshold that could be dangerous for the proper operation of the constructions works
Platform Wagon	Load Detection or Distance Sensors could be used to monitor and control the right position of the cargo on the wagon and alert the operators of falling objects which could damage other transported material or harm the workers. Depending on the shape and size of the transported material, the adequate sensor will be selected.
Gas or Liquid Wagon	A thermocouple is used to monitor the temperature of the gas or liquid wagon during the journey, detecting the crossing of any thresholds that could be dangerous for the proper operation of the constructions works.

All the mentioned activities are undertaken in the rail yard: a specific place where all the building (or mechanical/maintenance) materials are stored. Emergency services and working site management and control staff are also located at this point.

As it was explained before, the core of the DEWI solution is the concept of the DEWI Bubble. A DEWI Bubble is a logical entity operating in a physical space delimited by the range of the wireless transmission technologies employed for intra-Bubble communications.

Only one DEWI Bubble Gateway will act as the main point of interface with the outside world (extra-Bubble) and it will be able to host one or more wireless sensor networks, where each WSN can operate with a different technology, including legacy standards.

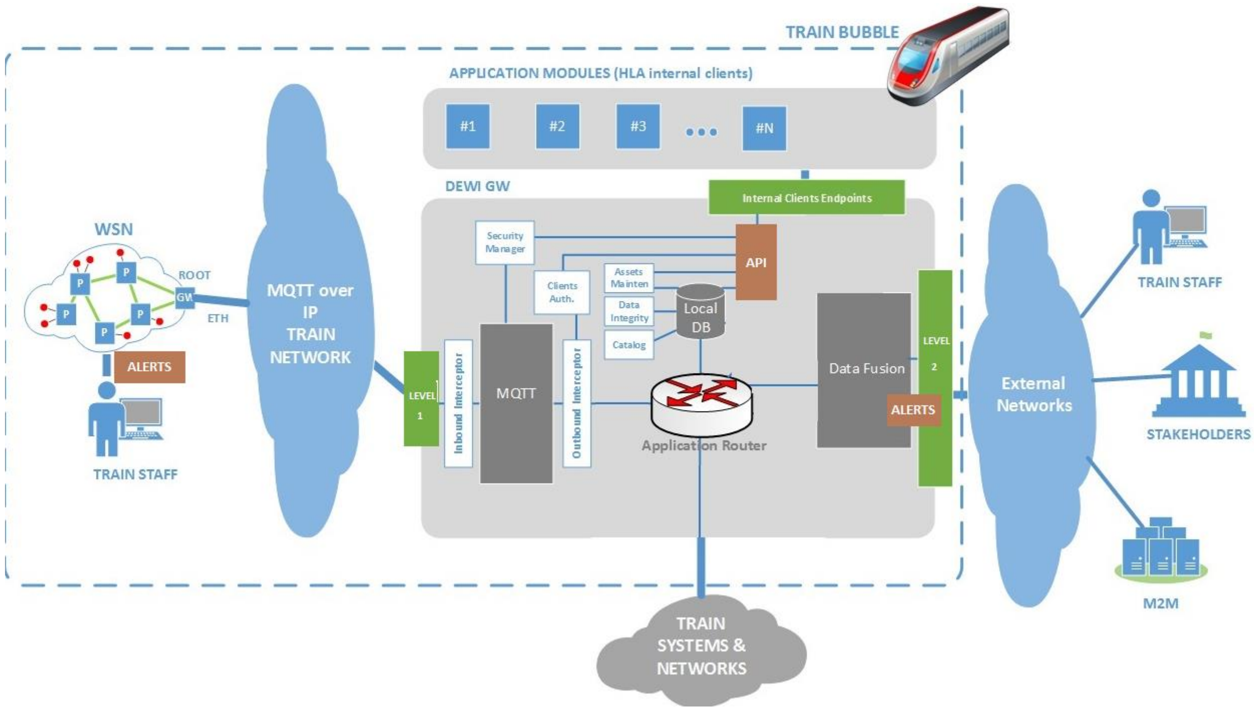

Figure 2 Logic diagram of DEWI Bubble in the Rail domain

The basic structure for ACCIONA WSN Monitoring System is composed by several WSN Nodes with one or more sensors in each one. At least one node for each network, called root node is in charge of collect all data obtained from the sensors nodes and transmit the information to the ACCIONA Coordinator, device in charge of controlling and configuring the sensor network, receiving and storing data (if it is needed) and sending information to DEWI Gateway.

The selected technologies for each level for this solution are:

Level 0: Based on 802.15.4 standard [5] in the 2.4 GHz band [6]. This wireless communication protocol is designed to use in low power devices with low-rates data transmission. There are different network topologies that these devices can use: point to point, start, etc. Data transmission between nodes is wireless through a wireless network with Mesh topology. In our solution, nodes are configured to use mesh networks, where each device capture and transmit its own data and collaborate to propagate data from other nodes to the central communication point.

In this communication infrastructure, each node has a list of other “neighbour” nodes. This list is sorted: the first node is the best option to send data and the last is the worst; the criteria used in this sort are out of scope of this document. When some data packet is ready to send or arrives from other sensor, each node sends data packets to “best neighbour” option, until the packet arrive to a central point where data is collected (also called “root node”) and sent to a storage area.

ACCIONA Sensor nodes provides their own communication infrastructure, and these are the main advantages:

- No additional communication infrastructure is needed.
- When any node is broken down, the remaining nodes which were communicating with it can recalculate routes and send data to another working node; therefore, the communications network is more robust compared to others (e.g. star, tree topologies) in the case that any node stops working properly.
- The network can be easily scaled up in large areas just with the addition of new sensing nodes.

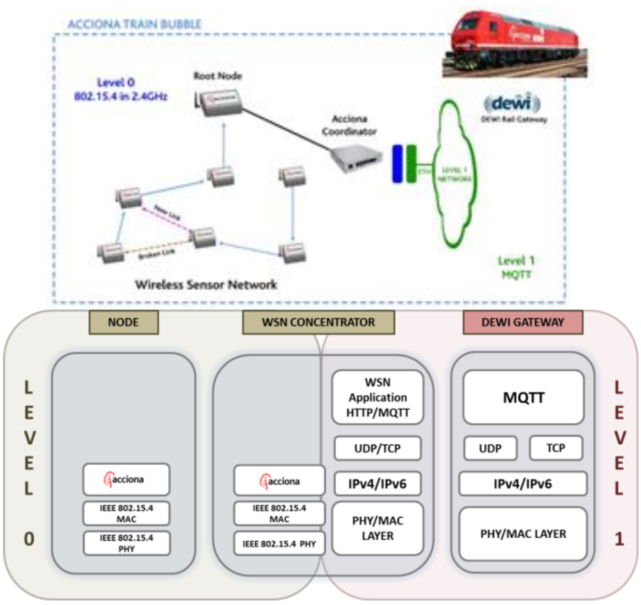

Figure 3 Data flow within WSN. Figure 4 ACCIONA WSN node communicating with server with communication stacks involving level 0 and 1

Level 1: ACCIONA DEWI nodes inside the WSN use an architecture and/or communication protocol different from the one used to communicate to the DEWI Gateway. Hence the WSN concentrator needs to manage the access to the bubble, manage the underlying nodes as expected in its architecture, and manipulate packets to a format DEWI Gateway is able to construe (and vice versa). This case breaks the architecture into two tiers, separating completely the ACCIONA WSN from the DEWI Gateway, with the need of a complex concentrator. The Level 1 protocol chosen has been Oasis MQTT [7] because is a loose coupling of publishers and subscribers, as both can work abstracting from the other and ignorant of system topology (on client/server paradigm the client cannot send data unless server is running, and server cannot receive unless client is running) and has a better scalability of the network, through parallel operation, message caching, tree-based or network-based routing, etc.

As a result of all the findings and decisions explained in the previous sections, the characteristics of the WSN to be deployed in the train are condensed in the following table.

Table 2 Features of the WSN for Underground Trains

Wagon	Sensors	Units	Location	Energy Supply	Sampling Frequency [8]	Latency [9]
Locomotive Cab	WSN Coordinator DEWI Gateway	1	Near the control panel	24V sockets	-	-
Locomotive Cab	Root Node	1	Near the control panel	24V sockets	-	-
Locomotive Cab	THL	1	Roof Cab	Rechargeable Batteries	1s	⩽ 1 second
Locomotive Cab	CO2	1	Near the control panel	24V sockets	30s	⩽ 1 second
Staff Wagon	THL	1	Roof Wagon	Rechargeable Batteries	1s	⩽ 1 second
Staff Wagon	CO2	1	Near the door	24V sockets	30s	⩽ 1 second
Bulk Container	CT	1	On top of the wagon	Rechargeable Batteries	5s	⩽ 2 second
Platform Wagon	Load Detection	1	Near train wheels	Piezoelectric/Solar	30s	⩽ 1 second
Platform Wagon	Distance	1	Near train wheels	Piezoelectric/Solar	30s	⩽ 1 second
Gas/Liquid Wagon	CT	1	On top of the wagon	Rechargeable Batteries	5s	⩽ 2 second

THL Temperature, Light and Humidity
CT Contact Temperature

3. Conclusion

So far, wireless technology is not widely used in underground construction sites. However, ACCIONA is sure that it can provide the base for developing new functionalities, like freight monitoring or increasing pre-existing functionalities like safety.

Proposed solution designed inside the scope of DEWI project, is focused on providing key solutions for wireless seamless connectivity and interoperability in rail tunnel infrastructures.

ACCIONA expects to implement this solution in the near future and, in this way, ease maintenance, reduce installation costs and increase safety levels not only in underground construction sites, but also in other kinds of sites that will be managed all over the world.

Acknowledgements

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Application of UAS for Nuclear Plant Containment Building Inspection: Lessons Learned from Testing the First Application

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Abstract

Inspection of cracks on the surface of tall concrete structures, including nuclear power plant containment buildings, often starts with visual monitoring, for which field crews need to climb up those cylindrical structures. In many cases, this practice takes time, cost significantly, and is dangerous. Korean Electric Power Corporation (KEPCO) has experienced this challenge for years while maintaining their nuclear power plants. Seeing how small Unmanned Aerial Systems (sUAS) are used for crop and livestock monitoring, one may be wondering if sUAS could be used to take pictures of cracks on the surface of the containment building. However, assuming that pictures need to be taken at a very close distance from the surface of the containment building, and also knowing that the line of sight has to be maintained all the time between sUAS and radio controller, one can reasonably figure out some challenges in terms of controlling sUAS manually. As a first step to handle this challenge, a research team at Texas A&M University developed a computer application that controls sUAS to fly around a simple circular building autonomously while changing its elevations. This paper presents how this application works, and what we learned from our field test.

Keywords: concrete crack monitoring, unmanned aerial system, waypoint flight control.

1. Introduction

Korea Electric Power Corporation (KEPCO) is a company that was founded in 1898 with an objective to generate electric power in South Korea. It runs several units of power plants including 23 nuclear power plant units in operation, 5 units under construction, and another 10 units in the planning stage [1]. Learning from previous accidents in Three Mile Island in 1979, Chernobyl in 1986 and Fukushima in 2011 [2], no one can emphasize enough the importance of safety in operating and maintaining the nuclear power plant. Among many facilities in the nuclear power plants, the containment building is one of the critical buildings, as it should prevent radioactive substances from leaking even in the worst-case scenario. Therefore, the Korean Government Ministry of Science and Technology [3] mandates that the containment buildings need to be inspected periodically.

The visual inspection of the containment building often requires field crews to climb up to a higher elevation or employ special cranes to detect any cracks that would endanger the stability of the structure, which prevents them from inspecting the structure surface more frequently. In case of using telescope lens to monitor any crack developments, they even need to deal with distortion problems.

2. Small Unmanned Aerial Systems (sUAS)

Unmanned Aerial Systems (UAS), which is also known as Unmanned Aerial Vehicles (UAV) or simply drones, have been originally used for military operations. Recently, various small Unmanned Aerial Systems (sUAS) were introduced for commercial use and they have been used to take aerial photos or video footages of construction sites. They are also used for emergency and disaster management, traffic surveillance and management [4]. Metni and Hamel [5] proposed sUAS for periodical visual inspections of bridges without interrupting traffic flows, and

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obtained images of cracks on concrete surface with good resolution. Morgenthal and Hallermann [6] discussed the potential use of sUAS for visual inspection of vertical structures including chimneys, towers and other structures, where cracks can be developed in higher elevations. In a study reported by Niethammer et al. [7], a drone equipped with a digital compact camera was used to track a landslide, soil moisture changes, and landslide displacement. Ruzgiene et al. [8] demonstrated the advantages of UAV with respect to collecting aerial photos and converting them into a 3D model.

There are different models of sUAS, and some of the most important ones are Fixed Wing and Multirotors. The first ones are mainly used for aerial mapping covering large areas including mines sites and stockpiles. The second ones are used for detail inspection of hard-to-reach structures such as towers, bridges, and other structures [9].

3. Automatic control of sUAS

Some sUAS can be controlled with pre-defined waypoints or points of interests. For example, the 3DRobotics, one of the leading sUAS vendors in the U.S., offers various applications including Mission Planner, MAVProxy, DroidPlanner, Tower, AndroPilot, MAVPilot, iDroneCtrl and QGroundControl [10] for automating the flight of sUAS using pre-defined waypoints or points of interests. These applications use various sensors including gyroscope, barometer, accelerometer, and Global Positioning System (GPS) to determine the location, elevation, and directional angle of the sUAS in operation. Most automatic flight control applications are used in an open space to pick up a series of aerial photos or video footages of a site, which can be used later for producing a digital map or a 3D topography model. One may speculate then if the visual inspection of nuclear power plant containment buildings can be executed automatically by utilizing these automatic flight control applications.

To test if it is possible to inspect the surface of the nuclear power plant containment building automatically using sUAS, a research team at Texas A&M University developed two computer applications enabling sUAS to fly autonomously around cylindrical objects. These applications were developed for a specific sUAS called IRIS from 3D Robotics. This particular sUAS was chosen for this test because of its flight controller called PixHawk, which can be controlled through a computer application that one can develop based on the open-source led by Dronecode Project. The Dronecode Project is an open source project led by the Linux Foundation, and it facilitates to develop a collaborative computer application for the automatic flight of the sUAS.

The first application developed for this test is about having the sUAS to fly around a point of interest, starting with an initial height and elevating to higher altitudes with constant intervals for a number times pre-defined. Figure 1.a. has the snapshot image of the tablet or mobile application waiting for user data input for the longitude and latitude coordinate of the point of interest, radius, initial height, height step, and the number of iterations. With this inputs, the application is supposed to have the sUAS fly autonomously around the point of interest multiple times while elevating its altitude each time as shown in Figure 1.b.

The second application developed for this test is slightly different from the first application, as it is designed to change the radius of the flight once the sUAS reaches at a certain altitude. The sUAS keeps flying about the target point until it reaches the maximum height pre-identified by the user. Figure 2.a. shows the snapshot image of the second application, waiting for the user input, and Figure 2.b shows the flight pattern of the sUAS suggested by the application.

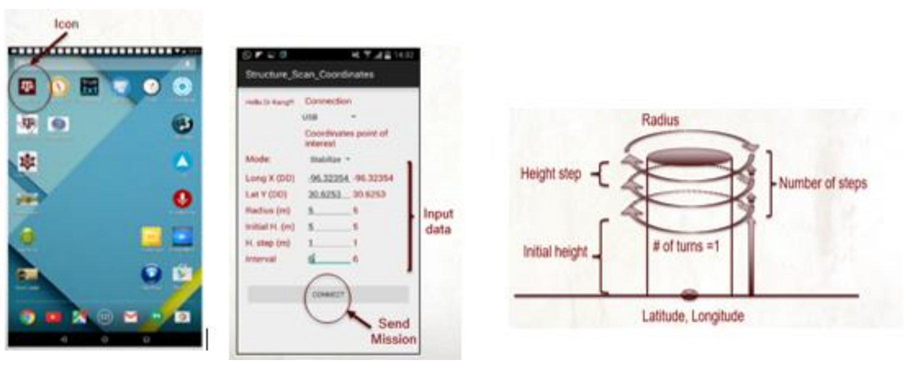

Figure 1: a. Snapshot of a tablet or mobile application 1 which controls automatically the flight of the sUAS (left and center), and b. flight path of the sUAS (right)

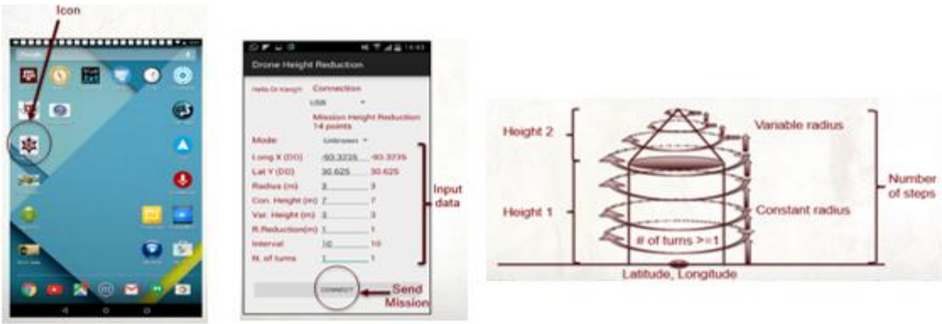

Figure 2: a. Snapshot of a tablet or mobile application 2 which controls automatically the flight of the sUAS (left and center), and b. flight path of the sUAS (right)

4. Field Tests

A field test was implemented in an open space, where a 6-meter pole was placed in the middle. The pole was wrapped with a masking tape in different colors for each an every 1 meter, so that it could be used later to measure the distance between the pole and sUAS flying around it through photos taken from the sUAS. An IRIS from 3D Robotics was used for this test, and a GoPro camera was mounted on the IRIS, which was setup to take time-lapsed photos every second.

The test started by having the IRIS fly autonomously as defined by the user inputs in the application 1 defining the initial height, interval between heights and radius of the circle that the IRIS would fly through. The GoPro mounted on the head of the IRIS kept taking photos every second. Theoretically, one can expect that these pictures would have the pole in the middle if the IRIS flew according to all setups.

A total of 385 pictures were taken from the test, and these pictures were examined to calculate 1) the distance between the pole and the IRIS, and 2) the offset distance of the pole from the center of the photo. These two data were used to determine the longitudinal and latitudinal position of the IRIS. The position of the IRIS could also be identified by collecting the GPS location information from the IRIS, however this test decided not to depend on it knowing that GPS location information carries a certain amount of errors. Figure 3 shows a sample photo taken from the IRIS. These basic dimensions are then brought to a CAD application, and used to determine that locations of IRIS when a specific photo was taken, as shown in Figure 4.

Figure 3: Photo G0024883 taken in a height of 3 m.

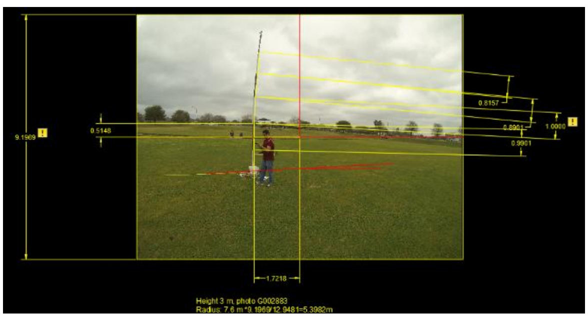

Figure 4: Photo G0024883 analyzed in a CAD application

5. Discussion

The test revealed that sUAS did not fly exactly as programmed. For example, as shown in Figure 5, the x components of the sUAS's location were offset somewhere between 1.5 meters and 3 meters. Currently, additional investigation is still going on to figure out what caused these tolerances. However, one can easily speculate that this might be caused by the native errors carried originally from the GPS. If these errors were caused by the GPS, then sUAS may not be engaged in automatic flight in a congested area such as nuclear power plant sites. Proximity sensors may need to be used in order to increase the accuracy level.

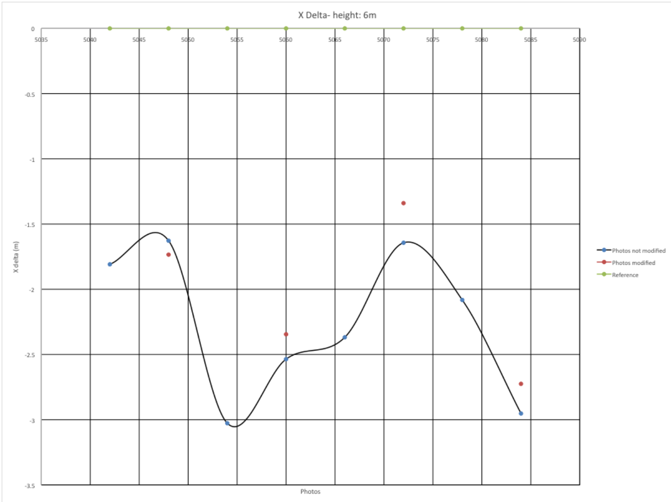

Figure 5: Horizontal distance in meters between the center of the picture and the pole's position per photo in a height of 6 meters

6. Conclusion

Two computer applications were developed to see if it is possible to control the flight of the sUAS for taking aerial photos in a congested area such as nuclear power plants. The application 1 was tested using IRIS from 3D Robotics, and it reveals the gap between the target position and actual position of the sUAS, which ranges somewhere between 1.5 meters and 3 meters. This tolerance level may not be good enough to get sUAS engaged in automatic flight for photo taking. It appears that additional devices such as proximity sensors need to be attached to the sUAS to increase the level of accuracy.

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A Suitability Analysis of Precast Components for Standardized Bridge Construction in the United Kingdom

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Abstract

This paper analyses the suitability of precast components for standardised UK bridges. The conventional design and construction of UK bridges is often criticised for being inefficient and unsafe as the majority of the work is carried out on-site, which requires lots of time and temporary works. The concept of Design for Manufacture and Assembly (DfMA) is employed in this study to overcome the limitations of current bridge construction practice and to realize standardization of bridge construction in the UK. First, underlying DfMA criteria for bridge construction are identified and a suitability analysis of precast components based on the identified DfMA criteria is conducted via an interview and survey. Second, a case study on a bridge recently built for a highway bridge project is conducted to identify the feasibility of the potential precast components selected from the suitability analysis. The result of the case study demonstrates that the recommended precast components can be successfully used for future standardised bridges of the UK.

Keywords: Design for manufacture and assembly, precast components, standardised bridges, suitability analysis

1. Introduction

The traditional bridge construction process is often criticised as being inefficient and unsafe [1]. The underlying reason for this is the nature of the construction where the majority of the work is carried out on-site. In fact, the design and construction of bridges in the UK has not been standardised or commoditized, resulting in costly and time-consuming construction practices. To address this problem, trials of off-site manufactured precast components for standardised bridge construction have increasingly been explored, inspired by the US Accelerated Bridge Construction (ABC) programme [2] which utilizes a variety of precast components including piles, piers and full-depth deck slabs. However, the use of precast components in the UK is limited to a few types such as precast beams and precast piers/columns. Hence, there is a need to investigate and identify the suitability of all types of precast components for the standardization of bridge components. The concept of Design for Manufacture and Assembly (DfMA) is employed in this study to meet the needs of the bridge standardization. The objectives of this study are two-fold: (1) identify specific DfMA criteria to be used for the evaluation of precast components for the standardization of bridge construction; (2) analyse the suitability of precast components based on the criteria identified. The rest of the paper is as follows. A brief review of DfMA is presented in Section 2, followed by the identification of detailed criteria for future standardized bridge components in Section 3. Section 4 analyses the suitability of precast components based on the identified DfMA criteria. Section 5 presents a case study on a bridge project adopting the DfMA approach to investigate the feasibility of the potential precast elements. Finally, Section 6 concludes with a summary of the paper.

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2. Research background - Design for Manufacture and Assembly (DfMA)

DfMA is an approach to design that focuses on ease and efficiency of manufacture and assembly [3]. This approach is driven by the need to produce large numbers of high-quality products, so widely adopted in sectors such as the automotive and consumer-products industries. DfMA is the combination of two methodologies: (1) Design for Manufacture (DfM), which means parts are designed to make their manufacturing processes easier, and (2) Design for Assembly (DfA), which means the product is designed to allow easy on-site assembly. There are a number of benefits of using DfMA approaches: (1) *Reduced Manufacture & Assembly Cost* - DfM seeks to reduce manufacturing costs by using fewer standardised parts and by eliminating unique parts wherever possible. This has follow-on benefits during the bridge assembly stage, because the use of standardized parts and the creation of a repetitive and familiar construction sequence can improve both the construction programme and quality performance; (2) *Shorter assembly time and increased reliability* - DfMA has the potential to reduce assembly time by utilising standardised components and rapid assembly practices. The use of digital modelling and visualization tools also allows for the simulation of assembly sequences prior to work commencing on site. This enables construction teams to become familiar with the erection sequence and methodology before setting foot on site. DfMA also increases quality and reliability by reducing variation in components and associated assembly processes, thus decreasing the chance of error on site. (3) *Shorter total time-to-market* - The development of a standardised kit of bridge parts/components with established manufacturing and assembly techniques allows designers to choose appropriate components from a library of components with well-defined design and detailing rules. This approach creates an opportunity for fast and efficient option selection during the conceptual design phase of a bridge project.

3. Research approach

General DfMA criteria are first identified based on underlying DfMA requirements which are widely adopted in the manufacturing industry. Then, specific criteria to be used for the evaluation of precast components for the standardization of bridge construction are developed based on the general DfMA criteria identified.

3.1 Identification of general DfMA criteria

A DfMA approach for product development aims to simplify the product structure and reduce manufacturing and assembly costs through enhancements in the design process [4]. Four common criteria for DfMA are listed below:

(1) *Simplification in design* - In the design phase, each bridge component should be checked using the following set of questions: Can the part be combined with another part? Can the part be standardised? Can the function be performed in another way? If so, a great deal of cost can be saved without compromising quality through lower material usage, reduced inventory and assembly costs.

(2) *Reduced number of parts* – Reduced the number of parts allows for a simplified design as fewer fabrication steps are needed during manufacturing. In addition, as the number of assembly parts decreases, the risk of errors during assembly decreases, therefore providing a more seamless assembly and disassembly process.

(3) *Standardisation of commonly used parts and materials* – Standardisation of commonly used parts and materials will decrease inventory costs while increasing the efficiency of handling and assembly operations. Furthermore, product development experimentation is not required, resulting in additional time and cost savings.

(4) *Ease of orientation, handling and assembly of parts* - Assembly parts should be designed to minimise movement, rotation and/or any other non-value-adding manual efforts for a saving in time and cost.

3.2 Development of detailed DfMA criteria for bridge components

Details of UK bridge construction are here investigated focusing on three aspects most relevant to DfMA as follows:

(1) Connection details - Connections are important parts of a bridge with regard to assembly time and cost. The connections between different precast concrete bridge components can be time-consuming to assemble and difficult to automate. Complexity in connections between bridge components can be reduced by minimising the number of connections and adopting an efficient joining and fastening system.

(2) Repeatability of components - Manufacturing processes have to be designed and developed so that a standard component can be reliably reproduced time after time, within required manufacturing tolerances. This is a process often referred to in manufacturing as 'repeatability'. The same component types can be used in different projects and thus a standardization often results in large economic cost benefits. The standardization in the

manufacture of bridge components can be achieved by designing casting moulds for producing various component types with a high degree of repeatable accuracy. Moreover, if manufacturing processes are standardized, then handling and assembly operations can be conducted more effectively.

(3) Suitability for manufacture - A design for manufacturability of bridge components is the process of proactively designing products to 1) optimize manufacturing functions such as fabrication, assembly, test, procurement, shipping, delivery, service, and repair, etc. and 2) assure the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction.

Detailed DfMA criteria were developed based on the DfMA criteria for bridges investigated above. Table 1 shows the specifications of the detailed criterion for each general DfMA criterion in terms of the manufacturing and assembly of bridge components. First, two requirements, 1) number of steps and 2) level of complex, were developed as the DfMA criteria with respect to the first general criterion '*simplification in design*'. The number of fabrication and assembly steps should be minimized as much as possible, and these steps should be simple. Second, the number of parts for both manufacturing and assembly processes should be minimized whilst meeting all functional requirements. Third, the components and materials selected should be standardised and common so that any further experiments on the components are not required. Fourth, the properties of the components (e.g. size and weight) should ensure that they are easily handled and placed during manufacturing and assembly processes. Lastly, steps of jointing and fastening should be kept to a minimum and the process should be as straightforward as possible.

Table 1. Specific DfMA criteria for bridge components

General criteria	Manufacturing characteristics	Assembly characteristics	Desired characteristics
Simplification in design	Number of fabrication steps	Number of assembly steps	Few
	Level of manufacturing complexity	Level of assembly complexity	Simple
Number of parts	Number of parts for manufacturing	Number of parts for assembly	Few
Standardisation of commonly used parts and materials	Are the parts standardised and made of common materials?		Standardised and commonly used materials
Ease of orientation of parts and handling	Properties of parts (e.g. size and weight) to be easily placed and manufactured	Properties of parts (size and weight) to be easily placed and assembled	Easy to handle parts and easy to manufacture and assemble
Ease of joints and fasteners	Number of joints and fasteners for manufacturing	Number of joints and fasteners for assembly	Few

4. Suitability analysis of bridge precast components

An evaluation of the most popular components, precast beams, was first performed to identify the suitability of precast beams for future standardised bridges. Table 2 shows the precast beams available in the UK market along with notes on their form and span range.

Table 2. Current precast beams used in the UK [5]

Beam	Section	Form of deck	Economical span range (m)	Depth range (mm)
TY-beam		Solid slab	4-17.5	400-850
Inverted T-beam		Solid slab	5-17	380-815
TY-beam		Beam & slab	7.5-17.5	550-850
Y-beam		Beam & slab	14-31	700-1400
SY-beam		Beam & slab	27-45	1500-2000
M-beam		Beam & slab	16-30	720-1360
U-beam		Beam & slab	14-34	800-160

An interview was conducted with a senior engineer from the largest precast beam supplier, Banagher Inc. [6] as the means of evaluation. Two measures were used for the evaluation: (1) popularity and (2) suitability with respect to the DfMA criteria identified in Section 3. In the interview, the respondent was asked to assess the popularity and suitability of each precast beam using five options (Very High (VH), High (H), Medium (M) and Very Low (VL)). Six types of precast beams were chosen as possible options based on their availability in the UK market for each bridge span of 10-20m and 20-40m, respectively. Table 3 shows the popularity evaluation results. TY and MY beams turned out to be the most popular components for bridge spans of 10-20m while W beams are the most popular choice for bridge spans between 20-40m followed by Y and U beams. Tables 4 and 5 detail the suitability results evaluated based on the DfMA criteria. Solid box, TY, Y, and MY beams are evaluated as highly standardized and simple in terms of manufacturing and assembly for spans of 10-20m, while Solid box, Y, U and W beams are evaluated as suitable components for spans of 20-40m. Based on this evaluation, five precast beams (TY, MY, Y, U and W beams) were selected as potential DfMA components for future standardised bridges.

In addition, a suitability analysis of 8 other precast bridge components currently manufactured was also performed. The assessment was conducted using a qualitative evaluation since these precast components are not as popular as the precast beams and fewer types are available in the market. Two criteria were used, (1) simplicity in design and manufacture, and (2) availability. Table 6 presents the findings and shows that all the precast components investigated (edge beams, parapets, permanent formwork panels, cill beams, piers/columns with crossheads, retaining walls, abutments and precast box panels) have potential as future standardised DfMA components, indicating that the most common bridge components can be configured and delivered using standardised off site manufactured components.

Table 3. Evaluation of precast beams based on popularity

Span 10-20m	Popularity	Span 20-40m	Popularity
Solid box beam with in-situ infill deck	M	Solid box beam with in-situ infill deck	L
TY-beam with in-situ infill deck	VH	U-beam with in-situ solid deck	M
U-beam with in-situ concrete solid deck	M	Y-beam with in-situ solid deck	M
Y-beam with in-situ concrete solid deck	M	SY-beam with in-situ solid deck	L
M-beam with in-situ concrete solid deck	VL	M-beam with in-situ solid deck	VL
MY-beam with in-situ infill deck	H	W-beam with in-situ solid deck	VH

Table 4. Evaluation of precast beams based on the DfMA criteria for spans 10-20m

	Simplification of design	Reduction of parts	Standardised parts	Ease of handling
Solid box beam	VH	VH	VH	VH
TY-beam	VH	VH	VH	VH
U-beam	M	VH	VH	M
Y-beam	VH	M	VH	VH
M-beam	M	M	VH	M
MY-beam	VH	VH	VH	VH

Table 5. Evaluation of precast beams based on the DfMA criteria for spans 20-40m

	Simplification of design	Reduction of parts	Standardised parts	Ease of handling
Solid box beam	VH	VH	VH	VH
U-beam	VH	VH	VH	M
Y-beam	VH	M	VH	VH
SY-beam	M	M	VH	VL
M-beam	M	H	VH	VH
W-beam	VH	VH	VH	M

Table 6. Qualitative evaluation of other bridge precast components

Component		Qualitative Evaluation	
		Simplicity in design and manufacture	Availability
Superstructure	Precast edge beams	These components are highly standardised and designed with their counterpart components, precast beams, indicating simplicity in design and manufacture.	TYE, MYE and YE beams
	Precast parapets	These components are normally designed with precast edge beams so that the design of these components can be easily conducted.	Parapets with TYE, MYE and YE beams
	Precast permanent formwork panels	These components are mostly rectangular with a constant thickness, resulting in simple design and manufacturing.	Panels with TY, Y, U and W beams
	Precast cill beams	These components have simplicity in its design and manufacturing. The use has been validated in recent projects such as the A453 bridge project.	Few
Substructure	Precast piers/columns and crosshaeds	These components have simplicity in its design and manufacturing. The use has been validated in recent projects such as the A453 bridge project.	Few
	Precast abutments	These components have simplicity in its design and manufacturing. They have been designed and manufactured using the shell-type structure, and the use has been validated in recent projects such as the A453 bridge project.	Few, shell-type panels
	Precast retaining walls	The design and manufacture of these components are not as simple as the other precast bridge components.	Single, double heel solid type and shell-type
	Precast box panels	These components have simplicity in its design and manufacturing.	Solid box and Shell-type panels

5. Case study – Soar Floodspan Viaduct Bridge

A case study on a bridge recently built for the A453 widening project [7] is presented to identify the feasibility of the selected precast components. The new bridge, which adopted the DfMA concept, is a five span viaduct, with an overall length of approximately 96m and a width of 13m as shown in Figure 1. The prefabricated components employed in the bridge are precast (1) Y beams, (2) edge beams (YE beam), (3) crossheads (pier caps), (4) piers, (5) abutments, and (6) cill beams. Among the bridge elements, one bridge element, the precast crosshead, is here investigated to identify its feasibility as DfMA component with respect to installation on site.

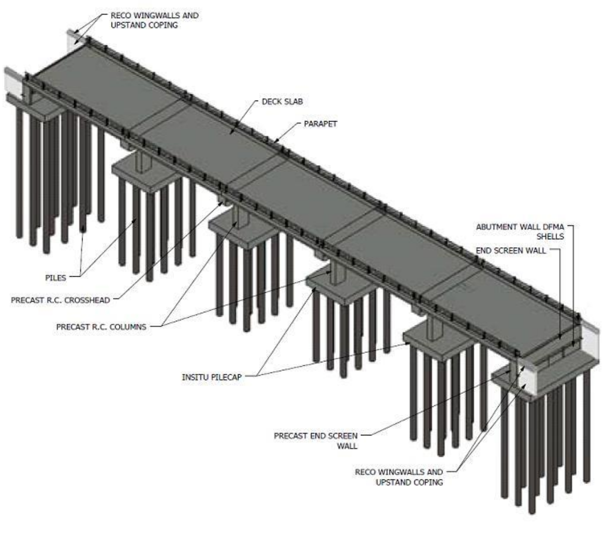

Figure 1. 3D view of the A453 widening project Soar Floodspan Viaduct bridge

Figure 2. Interface details between the precast crosshead and the precast pier: (a) 3D view of the precast crosshead and precast piers; (b) A photo of the connection between the two components

Figure 2 shows the interface details between the precast crosshead and the precast pier. The interface between the precast crosshead and supporting piers required accurate setting out of both the reinforcement projecting from the top of the pier and the void cast in the cross head (through which the reinforcement passes). The connection was achieved through the use of a laser cut template produced from the 'digital engineering' model. A full-scale mock-up was provided to understand the potential issues with cumulative tolerances. The link detail was also amended to prevent clashes. This digital bridge construction allows for pre-assembly manufacturing consideration and led to a successful installation on site, indicating that proposed DfMA precast components can be successfully used in near future bridge construction in the UK.

6. Conclusion

This study identified and selected precast components suitable for future standardised bridges in the UK. The concept of Design for Manufacture and Assembly (DfMA), popularly used for product development in the manufacturing industry, is employed to achieve the research goal of future standardization of bridge construction. First, specific DfMA criteria were developed to evaluate precast components for the standardization of bridge construction. Second, a suitability analysis of precast components based on the DfMA criteria identified was performed by conducting an interview and survey. 13 precast components (5 precast beams and 8 other components) were recommended from the suitability analysis for future standardised bridges of the UK. The result of the case study demonstrated that the DfMA-assisted digital bridge construction, where pre-assembly manufacturing is implemented prior to actual manufacturing and assembly, led to a successful installation on site, indicating that the DfMA precast components proposed can be successfully used in near future bridge construction in the UK.

Acknowledgements

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Information and Communications Technology in Construction: A Proposal for Production Control

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Abstract

It is very easy to verify that production information systems in construction works are still based on telephone, written media and intensive use of email; likewise, tracking and monitoring are carried out by taking isolated work samples of certain activities, which often give us a local view instead of a global view of productivity, leading to erroneous diagnosis and decision-making.
This paper presents a proposal of a system and technology for production control in construction that promote the commitment of the workers themselves, who draw up their self-reports using electronic devices and web applications that permit a simple and user-friendly data collection from their worksite. Additionally, the proposal includes processing information in the web that facilitates an easy and unlimited access for all the stakeholders of the project, wherever they are in their own computers, tablets or smart phones.
Having this information available, we can keep a productivity effective control, so we can have access to highly specific levels of production. Therefore, we can find out the root causes of both losses and savings in each construction process, providing the necessary support for a good feedback and the corresponding corrective measures.
In light of the results obtained in this trial stage, we believe that the system proposed will improve the production control level in construction works and make it technological and automated, thus improving the quality and productivity of works, and achieving a holistic conception of construction, with an active participation of all stakeholders throughout its execution.

Keywords: automation; Information Systems in construction; ICT in construction; mobile devices; production control

1. Introduction

If we want to talk about improvement, of either companies or businesses from any field, we necessarily fall under the shadow of *Kaizen* or Continuous Improvement, which proposes putting into practice the Shewhart Cycle, better known in Japan as Deming cycle, since it was Dr. Deming who made it public, or PDCA cycle (Plan–Do–Check–Act) [1-3].
In the civil construction field, applying this cycle consists of improvement-oriented planning, execution, evaluation and corrective measures; however, in practice, the third stage—the one pertaining to assessment—is not successfully complied with. To a great extent, this is due to the fact that information about the use of work resources is not reliable or is not available when necessary [4].

This article proposes an information system and technology to collect data directly from the worksite and process it on the web, thus we will be able to assess and control a construction site continuously, track every activity, and have access to it from wherever we are. This system was already patented by its authors several years ago with excellent results, but now we are incorporating in this new proposal the technology to automatize both data collection and processing. Said system collects data from the three resources of production through electronic devices and process it with an on-line software available in a web application.

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The Workforce resource is reported through touch screens by the workers themselves in the late morning, and in the late afternoon at the end of each shift. Material consumption is recorded on line tracking the materials that left the warehouse and were later consumed. The use of Equipment, as the use of workforce, is controlled by the operators themselves. Finally, the work progress is reported online on a daily basis from their worksite through digital tablets using store-and-forward applications.

2. Managing Production Information in Construction Works

The quality of production information in construction works is not consistent with current times; in practice, often just at the end of the work can accurate information be obtained in a financial statement of income and expenses when it is already late. Apart from being late, the information delivered by traditional control systems is too grouped to be useful for controlling and planning decision making [5, 6].

In the last two decades, construction industry has shown great advances in the use of ICTs worldwide, even in small and medium-sized enterprises, as described by several authors [7-12]. However, as Dave et al [13] conclude based on the work of Tartari et al [14]: the "majority of ICT solutions within construction industry are applied to the peripheral processes" and "site management and other construction related activities have remained virtually unaffected."

This is consistent with Bowden's studies [15, 16], which presents the existence of 85 paper-based tasks carried out on-site in their daily normal work. "These were grouped into different document types revealing the most commonly identified tasks as completing data collection forms (25%), dealing with correspondence (18%), viewing and reviewing drawings (13%) and reading and writing specifications (6%)".

The Information Technology and System proposed in this article reduce to zero the filling out of data collection forms about the use of production resources during the information collection process.

3. Proposed Information Technology and System

Our proposal focuses on production improvement: The first issue is to improve the quality of communication and information among the management, professional staff and work team, and the productive entity by building a bridge that efficiently completes the feedback-based improvement cycle.

The proposed data collection is described below:

3.1. *Defining the Baseline*

Before the commencement of the construction work, it is necessary to define the baseline against which the tracking and control of production is going to be compared. This baseline is made up of construction Time, Cost and Scope; therefore information about work budget, activities schedule and technical specifications must be previously entered in the system.

3.2. *Collecting Information about the Use of Workforce and Equipment*

The main proposal of our system focuses on breaking the deep-seated paradigm, especially in the construction sector, which is managing works according to Theory X. Whereas this theory considers that the workers cannot control themselves, cannot be motivated, and just work for money [17], our system supports on Theory Z, proposed by William Ouchi and intermediate point between Mac Gregor's Theory X and Theory Y [18], which considers that the workers are not motived only by money but also by new challenges and the trust that their company may place in them.

By delegating the responsibility for information to the production source, i.e. the workers, a permanent control is available, not over discretionary samples, but over 100% of activities and 100% of resources. Therefore, when workers are getting off work and at lunch, they go to the registration site, identify themselves using a biometric face reader (Figure 1), and make a self-report about the time destined to each activity (Figure 2) using touch screens.

The web application developed for this operation was designed to be user-friendly, so it does not pose any obstacle for workers to execute this action. The identification of activities shows images to help them easily identify the activities performed, while the display of images on the screen is automatically customized to the worker's profile after his identification. This requires less effort and it is easier for workers to draw up self-reports about the time spent in each activity.

Figure 1. Worker identification and self-report.

Figure 2. Worker self-report on a touch screen.

Before entering the worksite, new workers watch a 30-minute video as training that easily and readily explains the information system, the importance of this system for the company, and how they can participate. Every new worker must watch this video and take a short guided test on self-reporting. Additionally, workers who have operated equipment or machinery must also make a report, in a similar manner, about how long they have been operating them.

3.3. *Collecting Information about the Use of Materials*

All material that enters the worksite must be registered in the warehouse. For this task, the storekeeper has access to the system that allows him to directly register it on the web, recording also the quantity received and unit cost. Then, when these materials are required to be used, he must also record their exit, showing the quantity and destination record.

3.4. *Collecting Information about Work Progress*

Due to the nature of production in construction, work progress is recorded on site, going around the worksite registering information in different places where tasks have been carried out. This information is collected by a person in charge at the end of the workday using a digital tablet (Figure 3). This procedure helps save time normally spent to transfer the collected data—generally on paper—to a control system, that in most cases is done in an electronic spreadsheet. In order to avoid that the lack of Wi-Fi in the worksite where we record the work progress becomes a restriction, an application for mobile phones with the store-and-forward feature is used allowing information to be temporarily stored in the device (figure 4) and then automatically uploaded on the web as soon as Wi-Fi is available.

Figure 3. On-site work progress registration.

Figure 4. Use of digital tablets and store-and-forward

3.5. *Production Reports*

Once the system has all the daily production information uploaded on the web, several reports will be available to track, control and have a quite clear idea of the global workforce productivity at any time given time. The different reports can be accessed at any stage of the works with one-day accuracy and the performance diagnosis can be obtained within the periods matching the dates when the work progress was recorded, thus reaching a 100%

control of the works without bearing excessive control staff expenses, since the system is practically run by the workers themselves.

By reviewing each user profile, the different stakeholders can have access to different reports according to their needs. For instance, crew leaders and the foreman can check their staff performance; contractors can track their staff if they also participate in this system; storekeepers can check all incoming and outgoing materials as well as valued stock; administrative offices can get updated information on staff assistance to calculate payrolls; professionals involved in the works can check the details concerning schedule, costs and performance of each activity; or the management can check the production ratios, the actual results, and the results projected for the end of the works.

Figure 5 shows us the traditional information flow corresponding to the production in construction works, while Figure 6 shows the same flow with the system we propose implemented. The benefit we obtain by simplifying the collection, transfer, storage, processing, distribution and communication of data for the stakeholders can be clearly noticed.

4. Contribution of the system for the Continuous Improvement

Feedback in construction works is managed late with approximate figures, isolated samples, and not very trustworthy information, which prevents us to implement a continuous improvement cycle in an effective manner. Thanks to this system, the information is continuous and permanent. And since monitoring what was executed is carried out with the same accuracy as monitoring what was planned, we have the opportunity to receive a very efficient feedback the next day from the moment each budgeted record is executed. Additionally, this system shows us the root causes behind why the executed activities did not meet the planned goals to take corrective measures, get lessons learned, modify processes, propose innovations, etc.

Having this web-based system makes it possible to share the information with all the stakeholders, thus providing a feedback in different directions, promoting proposals of continuous improvement supported on a collaborative teamwork. An important aspect is the fact that the Management is one of these stakeholders. Normally, due to restrictions of time, distance, access, or poor communication, the Management loses its connection with on-site problems, i.e. it loses its involvement and support to continuous improvement programs for the projects. On the other side, we have the workers who are contributing now with the system in a significant way, making them important agents for project development.

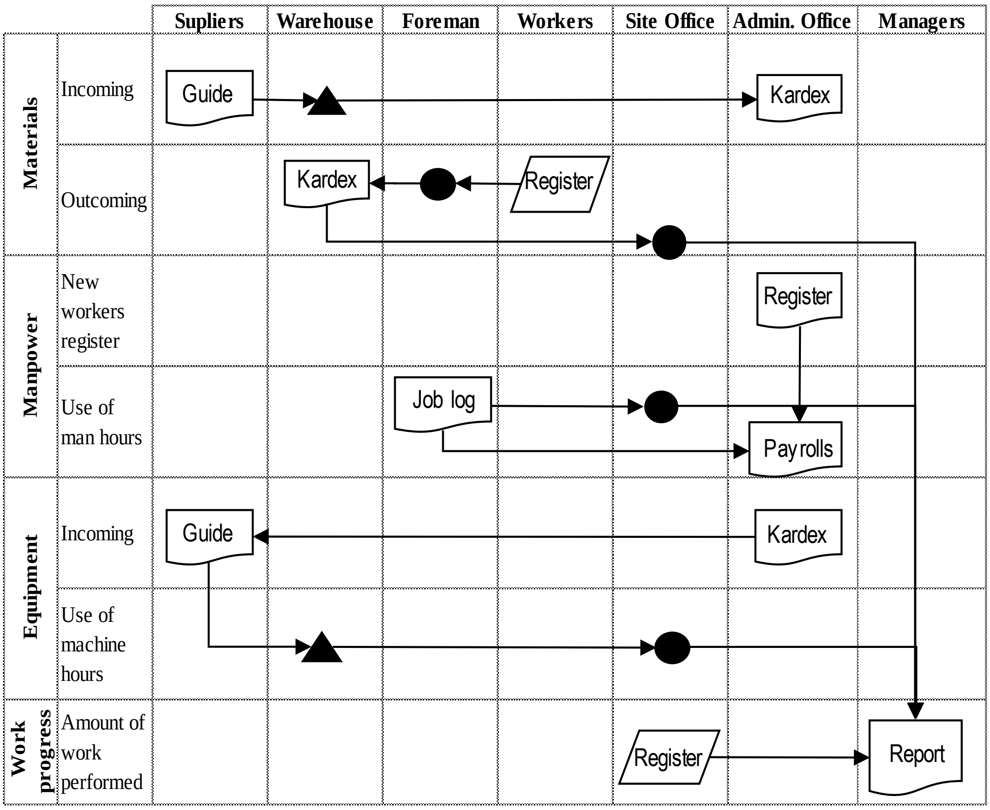

Figure 5. Traditional production information flow.

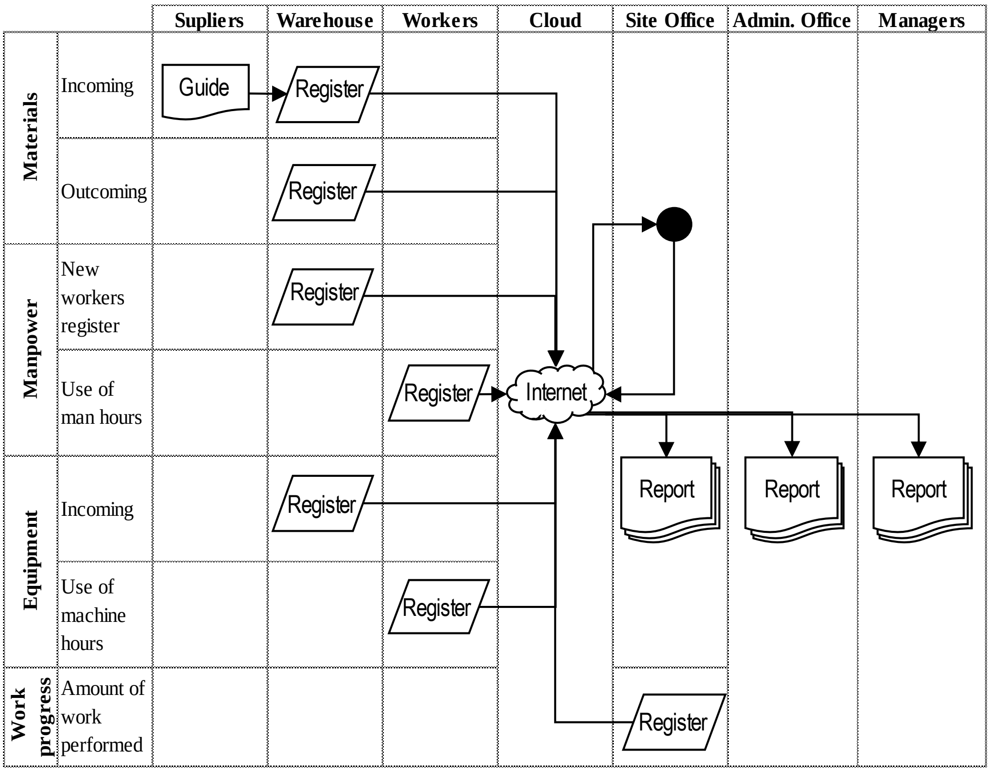

Figure 6. Production information flow with the proposed system.

This constant feedback allow us to evaluate innovations, since we can compare the new results with the ones before the implementation and have a historical data bank for the company, enabling us to plan future projects.

5. Conclusions

The system we propose is based in 3 main points: 1). Transfer the task to obtain most of the production information to the workers. 2). Use web applications to promote collaborative work to enter data and information shared distribution. 3). Use electronic devices to make information collection easier.

The first point - considered crucial and questionable - has been a daily successful practice in all the works our company carries out for many years. The second point also shows the same scenario, since we already have an intranet containing a module with the presented proposal that is extensively approved by all the stakeholders. On the other hand, the third point is an innovation indeed, which is in pilot testing, that we intend to use to complete the missing link to create an efficient Continuous Improvement Cycle application for the construction sector.

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Ontology-based Emergency Plan Management of Metro Operation and its Application in Staff Training

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Abstract

Emergency plans play a key role in the emergency management of metro operation. Well-prepared emergency response supported by plans can greatly mitigate the significant impact of metro incidents. However, most emergency plans remain as plain-text documents, which make it difficult to conduct efficient administrative work such as plan creation, preservation and maintenance. Operational use of plans such as rapid knowledge retrieval and acquisition can’t be performed as well, affecting emergency training during preparation process as well as plan review at the scene of the accident. Additionally, the knowledge coded in emergency plans are mostly depicted by texts, which are not vivid and intuitive enough to clearly display the instructions of response procedures and relative information. In this paper, an ontology-based knowledge modeling method has been proposed to improve the knowledge management efficiency, and a unified and formalized knowledge repository of plans can be built based on it to facilitate the efficient administrative and operational use of emergency plans. BIM technology has been introduced to provide a realistic visualization of the plan knowledge for better understanding. A prototype of emergency plan training system for metro staffs, which integrates BIM and the ontology-based knowledge repository, has been developed to demonstrate the feasibility and effectiveness of the method. A case study has illustrated the knowledge management process and shown how staff training can benefit from the system.

Keywords: Emergency plan; Metro operation; Ontology; Training system

1. Introduction

The increasing scale of metro construction as well as the booming passenger flow have set higher demand for the emergency management of metro operation. As the first couple of hours after the incident occurrence play the most crucial role in fighting and mitigating the impacts of the incident on passenger’s lives [1], timely and high-quality emergency response are crucial to ensure the public safety. In order to quickly respond to metro incidents, a large amount of emergency plans covering all possible incidents relative to operation areas have been developed by local metro operation companies to prepare for the response process. Emergency plan serves as a manual that describes procedures for dealing with all kinds of emergencies [2], and on-site emergency command and relief work can be greatly supported by it. Also, for better response performance at the scene, the plans will be learnt and memorized during metro staffs’ professional training so that they can act quickly after the occurrence of a real emergency.

However, more than 80% emergency plans of metro operation in China are plain-text documents or rigid electronic files without semantic meaning, which make it difficult to conduct efficient administrative work such as plan generation, preservation and maintenance. This inefficient management of emergency plans also cause inconvenience in the use of plans. Large amount of the plan knowledge scattered among various files without organization has made it impossible to conduct rapid knowledge retrieval and acquisition, seriously affecting the advanced emergency training as well as the on-site knowledge support. Thus, it is essential to organize and represent the knowledge in a structured and coherent manner to promote the efficiency in both administrative and operational use of emergency plan.

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Meanwhile, the knowledge coded in emergency plans are mostly depicted by texts, and some descriptions of response procedures are not specific and explicit enough for a good understanding of the information contained in them. The characterization of the emergency conditions like station features and rescue resource availability has not be considered, which leads to the lack of pertinence and effectiveness of emergency plans. Therefore, combining response procedures with its associated contextual information is important to enhance the applicability of the plan knowledge, and a more visualized method of knowledge display is needed to extend the capacity of metro staffs to better understand and memorize them.

In this work, ontology has been introduced for knowledge management support. To overcome the weakness of traditional file management of emergency plans, an ontology-based knowledge modeling method has been proposed to improve the knowledge management efficiency. The vast knowledge of emergency plans can be structured and represented based on a unified and explicit knowledge framework to establish a structured and formalized knowledge repository. Efficient administrative and operational use of emergency plans can easily achieved with technical support.

To enhance the applicability and visualization of the plan knowledge, BIM technology has been exploited to integrate contextual information associated with the response procedures, and specific and intuitive knowledge display of emergency plans has been provided. To demonstrate the feasibility and effectiveness of the method, a prototype system of emergency plan training for metro staffs, which combines the ontology-based knowledge repository and BIM, has been developed to support the efficient emergency plan training process for metro staffs. A case study has illustrated the knowledge management process and shown how staff training can benefit from the system.

The remainder of this paper is organized as follows: In Section 2, we briefly discuss the related work in knowledge management of emergency plans and BIM application in them. Section 3 presents the ontology-based knowledge modeling method of emergency plans for metro operation. Section 4 discusses the establishment of the prototype system of emergency plan training for metro staffs. Section 5 illustrates an example of application. Finally in Section 6 we conclude the work, discuss the prospect of the ontology-based emergency plan training system for metro staffs as well as future study directions.

2. Research review

For better management of emergency plans, IT-enable method has been studied by different researches to improve administrative efficiency and practical application effect. Dong, Li and Xu [3] have developed an information management system to enhance the automatic management of emergency plans such as adding, deleting, modifying and inquiry of plans. Canós et.al [4] introduced SAGA, a framework designed to provide support to the full lifecycle of emergency plan management and use. The information management system proposed by Mejri [5] has introduce ontology for the analysis of information function during the entire workflow of emergency management. Wang, Yang and Dong [6] have built an emergency plan system ontology to promote the communication and sharing between different plan systems. To enhance the applicability of plan knowledge by integrating contextual information, Canos, Alonso and Jaen [2] have proposed the concept of hypermedia plan which integrated the plan information with a 3D model of incident location on one screen. BIM is used to provide geometric information of the emergency scene for evacuation planning by Li et.al [7].

Although ontology has been introduced to solve the semantic lack existed in the traditional information management system of emergency plans, most researches built the ontology from the administrative perspective, which limited its further operational use for knowledge support during a real emergency. Besides, much of the environmental information of the emergency scene presented by BIM are mostly used to refine evacuation routes or support realistic visualization of emergency scenarios. The support for a better understanding of the knowledge contained in emergency plans are seldom studied. In this research, an ontology-based knowledge management of emergency plans for metro operation has been proposed to improve the efficiency both in administrative and operational use. The development of a prototype ontology of emergency plans for metro operation (Ont-EP4MO) will be firstly presented in the next section.

3. Development of Ont-EP4MO

As the most widely recognized definition said by Gruber [8], “Ontology is an explicit specification of a conceptualization.” It provides a way to move from a document-oriented view of knowledge management to a content-oriented view [9]. Another characteristic of ontology is formalization, which was mentioned by Studer et.al [10] to highlight its machine-readable feature. Hence, the ontology-based knowledge management of emergency plans for metro operation will facilitate the organization and standardization of plan knowledge, improving the efficiency in administrative work and operational use such as knowledge retrieval for emergency training or timely knowledge support at the scene.

3.1. *Knowledge modeling of emergency plans*

In order to achieve the ontology-based knowledge management of emergency plans, a common and standard knowledge framework of emergency plans should be built first, in which a common language is used to conceptualize the necessary information contained in these plans. After a study of national guidance and emergency plans of several cities, key concepts and relations are captured and extracted from these scattered sources for knowledge modeling, and a common knowledge model of emergency plan is built, as shown in Figure-1.

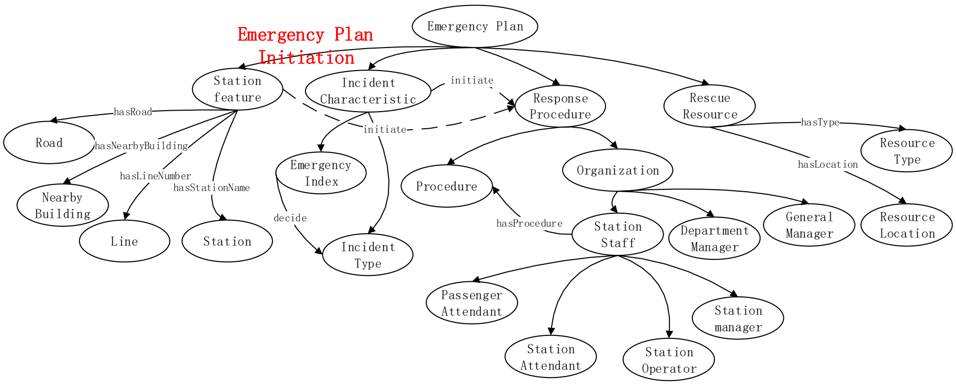

Figure-1 Knowledge model of emergency plans for metro operation

Four core parts of a complete emergency plan have been identified, namely station feature, incident characteristic, response procedure and rescue resource. The former two parts also form the classification standard of vast emergency plans. The most import part of the plan is the response procedure described for each position at the station. Incident characteristic is used to describe the basic information of the emergency such as incident type and emergency index. The information of rescue resources are needed to help with the action performance. The most essential relations between these concepts are constructed based on the initiation mechanism of an emergency plan, as shown in the dotted lines. After the occurrence of a metro incident, the real-time information of incident type and occurrence location shall be gathered immediately to launch the associated emergency plan, and then response procedures can be committed by station staffs respectively.

The knowledge model has provided a unified framework for the organization and standardization of all different kinds of emergency plans. Based on it, the knowledge of emergency plans can be stored in a common way to achieve the construction of a coherent repository. The advantage of information sharing and reuse of ontology has enable the efficient administrative work such as plan generation and maintenance, as well as a collaborative environment for different actor involved in the whole lifecycle management of plans.

3.2. *Knowledge representation*

After the unified knowledge model was built, a representation schema is needed to represent the knowledge in a formalized and explicit way with machine-readable language to facilitate computer-aided information retrieval and acquisition. OWL, as a common ontology language, has been used to define and describe the ontology elements. Moreover, the ontology model is implemented using protégé, which is a software that provides an easy and flexible interface to create an ontology. Based on the proposed knowledge model above, the basic elements such as classes and properties of the ontology can be constructed. Then, the specific information of different emergency plans can be stored as the instances of the corresponding classes, and a structured and formalized knowledge repository can be represented.

4. Emergency plan training system

As one of the most promising development in AEC industry, BIM can provide accurate virtual models in a digital way to support the management activities through the whole lifecycle of the building [11]. Semantically rich information including all geometric and functional properties related to the facility can be integrated into the BIM model, improving visualization as well as the understanding of the relevant management work. Considering the weakness of text-based knowledge display of emergency plans, BIM has been exploited to provide a realistic visualization of the plan knowledge for better understanding.

In this research, a prototype of emergency plan training system for metro staffs has been developed to demonstrate the effectiveness and feasibility of the ontology-based knowledge management. The architecture of the system are shown in Figure-2. Different emergency plans are collected to build the ontology-based knowledge repository, while 2D drawings of metro stations are used to construct a BIM database by Revit. The information retrieval and acquisition can be quickly performed based on the knowledge repository, while realistic visualization of the related plan knowledge can be presented based on the BIM database. Four function modules are built to perform the plan knowledge learning from four aspects mentioned in the knowledge model above.

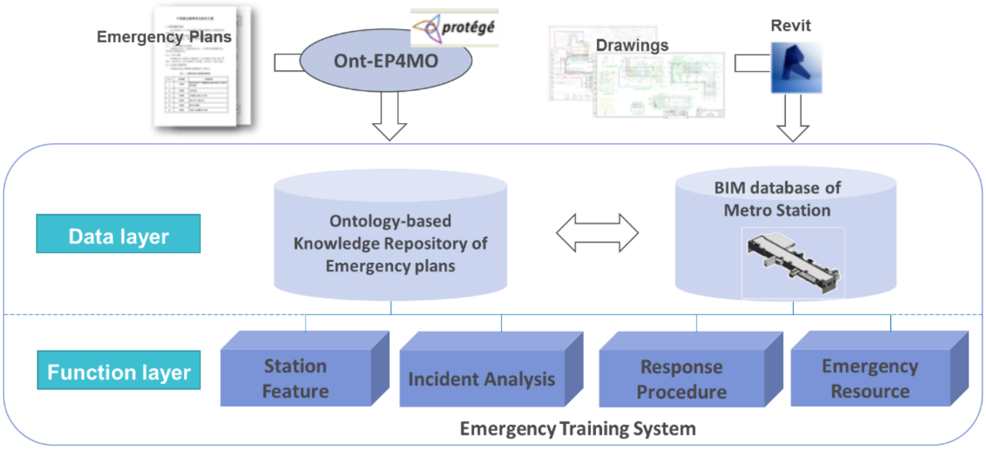

Figure-2 System architecture

5. Case study

To demonstrate the effectiveness of the system proposed above, emergency plans for the incident type of passenger flow surge in Wuhan ZhongNan Road Station has been stored as instances of Ont-EP4MO in the construction of the knowledge repository, and the BIM model of the station was built to provide visualization of the plan knowledge. Based on the emergency plan, the severity of passenger flow surge has been classified into three levels. The higher the level, the severer the situation is, and various response procedures will be inferred based on the level and the staff position previously set. The passenger flow thresholds of each level for both station hall and platform have been set up. A partial exemplified illustration of how the knowledge can be used to populate the corresponding concepts and the relations of Ont-EP4MO is given below, as Figure-3 shows.

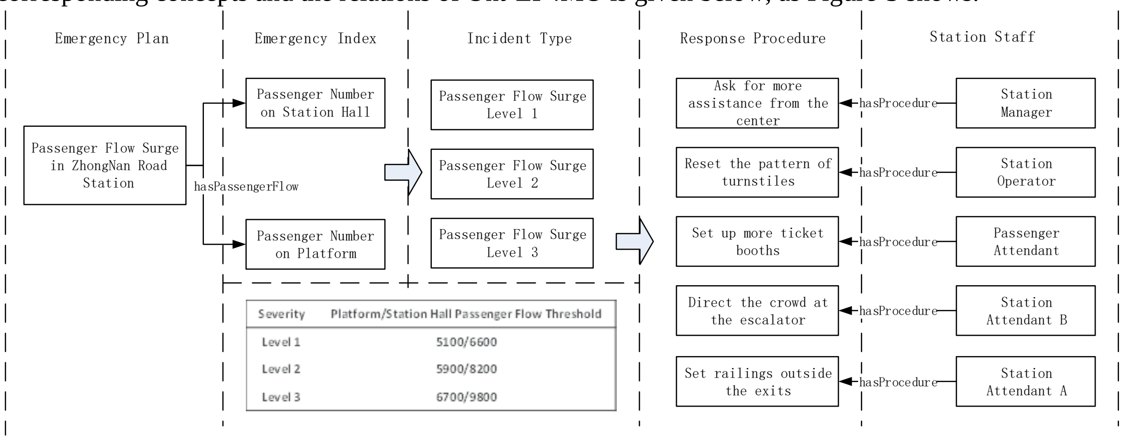

Figure-3 Knowledge repository construction

5.1. *Knowledge reasoning and acquisition*

The ontology-based reasoning can be efficient for knowledge retrieval and acquisition based on the constructed knowledge repository. The rules of level identification and procedures acquisition are presented by SWRL (Semantic Web Rule Language), as shown in Figure-4. If the number of the passengers stay on the platform exceeds the threshold of level 3, the incident type will be reasoned as “Passenger_Flow_Surge_Level3”. The response procedure “direct the crowd at the escalator” will be acquired according to the station position set as “Station_Attendant_B”.

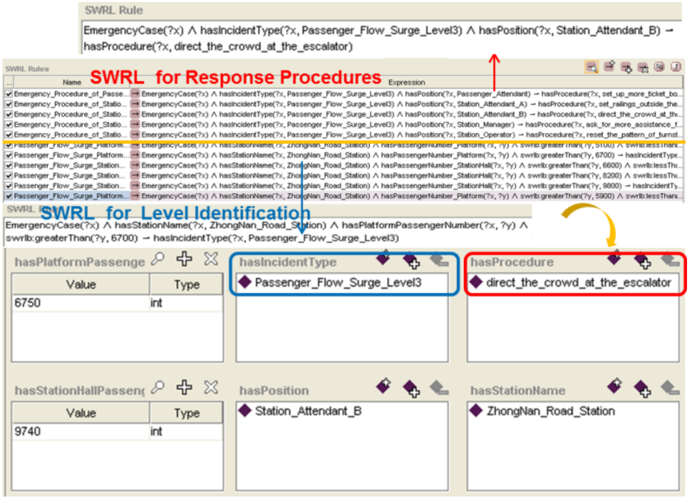

Figure-4 Knowledge retrieval of response procedures for passenger flow surge

5.2. *BIM-based knowledge display*

The BIM model of ZhongNan Road station has been built based on the drawings, as shown in Figure-5. The geometric and functional information are integrated in the BIM database, and the visualization of related plan knowledge can be obtained. According to the knowledge retrieval before, the station attendant should perform the emergency procedure of directing the crowd at the escalator. Hence, in the function module of “Response Procedure” of the system, the knowledge can be display in BIM-based simulation, shown in Figure-6.

Figure-5 BIM model of ZhongNan Road Station

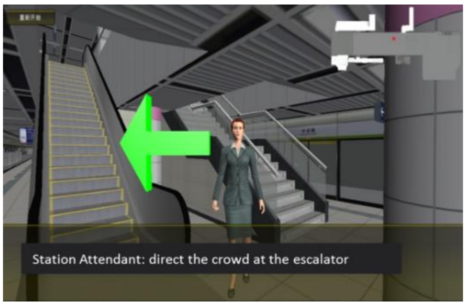

Figure-6 Visualization of response procedures

6. Conclusion and future work

Considering the inefficient management of paper-based emergency plans and the follow-up problems produced in emergency plan training for station staffs and knowledge support at the scene, an ontology-based knowledge management of emergency plans has been proposed to organize and represent the plan information in a standard and semantic way, enhancing the efficiency in both administrative and operational use. A prototype system of emergency plan training for metro staffs, which integrates the ontology-based knowledge repository and BIM technology, has been developed to demonstrate the feasibility and effectiveness of the method. The case study has shown the implementation of efficient knowledge reasoning, acquisition and intuitive training process.

However, two limitations are identified below: since the ontology was constructed only based on existed emergency plans, other important knowledge that haven’t been concluded in the plan may be missed. Interviews of professionals in the field of emergency management should be conducted for continuous refinement and evaluation of the ontology. The proposed training system should be testified by more station staffs to ensure its operability in practical applications. Further development of the emergency training system is the research direction.

Acknowledgement

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On-site Mobile Application for Command, Control and Communication of Safety and Quality

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Abstract

Safety and quality are two factors that play an important role in construction projects success. Management involvement in safety, effective communication and control during the construction phase have been identified as fundamental parameters that lay the foundations for effective construction. Focused on the emerging mobile computing technology, smartphones and tablet, an application for command, control and communication of construction safety and quality management was developed. The application makes use of tags, which are physically attached to the workers and equipment (such as scaffoldings, formworks and crane). All safety procedures can be implemented using the application, including, safety specifications, safety and quality checklists, forms, reports, safety risk assessment and safety and quality audits and records. The information can be accessed on real-time by all members of the project management team and senior company levels. To evaluate the applicability, the system was implemented in a pilot project. Safety and quality key performance indicators were established and implemented prior, during and following the implementation in order to examine and quantify the potential benefits. The observation of the key performance indicators provided a clear evidence of the potential of the proposed mobile application in improving both safety and quality of construction activities.

Keywords: Communication, control, mobile application, quality, safety management.

1. Introduction

Safety and quality in the construction industry are continuously under the spotlight of safety and quality control [1, 2]. In spite of the efforts to enhance safety performance construction fatalities and injuries continue to be a worldwide plague [3]. According to the Ministry of the Economy [4, 5], the Israeli construction sector continues to collect the highest death-toll compared to all others sectors of economy. In the years 2012 and 2013 construction industry mortality accounted for 52 and 50% of the total industry death toll [4, 5]. Furthermore, injuries and fatalities cause inestimable suffering, and are also associated with considerable financial expenditures caused by disabilities and early retirement [6, 7]. Besides, the cost of quality deviations in the construction industry has been found to be significantly high. Activities required repairing quality deviations represent a significant factor that contributes to cost and schedule overruns [8]. Burati et.al. [9] indicated that quality deviations in the projects accounted for an average of 12.4% of the total projects cost and Love et.al. [8] found that rework contributed to 52% of the project's cost growth. Thus, an integrated safety and quality management system could be useful tool to reduce the occurrence of injuries and fatalities and complete a construction work on schedule and within the allotted budget [1].

Management involvement, effective communication and control during the construction phase have been identified as fundamental parameters that lay the foundations for the safety and quality climate in construction. Furthermore, in literature there is a large qualitative consensus for integrated quality and safety management [2, 10, 11]. The advent of smartphones with the state-of-the-art of the mobile computer technology provides an important opportunity to improve the existing process of on-site construction management [12]. Although the recent attention by the researchers in the use of Information and Communication Technology (ICT) in construction

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[13], no empirical studies have yet investigated the use and benefits of the ICT for an integrated safety and quality management in construction. Exploiting the emergence of the mobile computing technology, the present study aimed to propose and test the above-mentioned system.

2. Background

2.1. *Safety and Quality in Construction*

Safety in the construction site is a complex phenomenon impacted by multiple factors such as the design quality, planning, safety equipment, workers safety qualifications, safety management, and control [14]. In order to investigate these factors, Choudhry and Fang [15] interviewed construction workers who had been accident victims. Management involvement and communication were found to be the most effective factors to encourage and facilitate site safety. Along the same line, Mohamed [16] concluded that both management commitment and communication are prerequisites to create and sustain a positive safety climate in the construction site. This conclusion was also reached and supported by other studies [17]. In addition, effective control by the site manager through inspections, supervisory key factors and over the subcontractors plays an important role to enhance construction safety. Abudayyeh [17] conducted a survey concluding that the injury and illness incidence rates of companies that performed safety inspections were significantly lower than those who did not. Zhang [3] revealed that about one third of the workers' unsafe behavior, which is the main cause of accidents, caused by lack of managerial or supervisory activities, and Mohamed [16] found that supervisory practices have a positive influence on the safety climate. Teo [18] reported that a major concern of the site managers, during the construction process, is the effectiveness of control over the subcontractors, as high number of subcontractors increases the probability of poor communication, coordination and control, and consequently the chances the likelihood of accidents.

Loushine [1] examined the definition of quality used in the literature. Researchers in construction gave the following definitions for quality performance: meeting expectations of the customer, reduced rework or defects, repeat business and completion on-time and within budget. Rework which was defined [10] as the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time. There are various forms that may require rework such us quality deviations and failures, nonconformance and defects [8]. Although rework is often associated with design related issues, a greater number of rework-related incidents tend to occur during the construction phase [19]. Love et.al. [19] studied the construction quality by identifying the factors that influence rework in projects. Lack of quality management, poor communication, and poor supervision and control were found as key factors that contributed to reworks occurrence. Along the same line, Arditi [20] found that during the construction phase, effective control and communication enhance the quality of the building process.

2.2. *Synergy between Safety and Quality*

Pheng and Pong [21] confirms that there are similarities between safety and quality management systems, and it make possible to integrate these two processes to achieve better co-ordination and utilization of scarce resources. Hursul et al. [11] argues that the similarity of the safety and quality functions and the fact that they operate simultaneously in the same environment leads to the conclusion that it might be beneficial to combine or at least closely coordinate the management activities. Hoonakker et al. [22] found that implementation of quality management systems in construction contributed to enhanced safety.

Despite the above findings, there is a lack of empirical studies to validate this hypotheses. In fact, only two recent researches had stressed this relationship empirically, by analyzing safety and quality data obtained from construction projects. Wanberg et al. [2] have provided an empirical evidence for a positive relationship between construction safety, and quality performance. Empirical data from 32 construction projects suggest the following relationships: (1) recordable injury rate is well correlated to rework, and (2) the first-aid rate is well correlated to number of defects. Trough interviews to project manager, it was identified that the reasons of these positive correlation are in the fact that rework involves demolition, schedule pressure and unstable work processes. Love [10] analyzed safety and quality data resulted from quality non-conformance, and found that 19 percent of safety incidents can be explained by rework.

3. Objectives

This research developed a mobile application for command, communication and control of construction (C4) safety and quality. The rationale behind this theme is the hypothesis that a synergy exists between high safety and high quality standards and vice-versa, and that a mobile application for the communication and control of these key construction subjects will introduce safety and quality in construction. An implementation of the application in a pilot study followed the development of the application to demonstrate and examine the applicability of the application. The objectives were as follows:

- To develop the C4 mobile application for continuous improvement of safety and quality performance in construction projects;
- To examine, measure and quantify the potential benefits resulting from the implementation of the system in a pilot project, through the use of safety and quality key performance indicators.

4. Description of the C4 mobile application

The C^4 mobile application aims to develop an innovative solution to continuous improvement of construction safety and quality by providing enhanced capabilities for control, learning and implementation of all measures necessary to ensure safety and quality. The proposed solution relies on mobile cloud-based system and of the methodologies for managing safety and quality according to the principles of the relevant Israeli Standards (e.g. 904 (formworks for concrete) [23], 118 (concrete) [24], 466 (concrete structures stability) [25]) and following the safety regulations of construction operations. The developed application allows ensuring that before workers start to perform a certain activity, action, place, time and people entitled to the operation are uploaded in the system. Tracing and documentation are carried out in few seconds by scanning the barcode label smart, using a mobile phone or tablet. Each tag code is unique to each asset and workers. The scan function allows the holder to make all relevant information, including: safety specifications, safety and quality checklists, forms, reports, safety risk assessment and safety and quality audits and records related to the place or the equipment it comes into contact with them, as showed in Fig.1. Construction managers and foreman are in charge to register workers and work tasks information, including description, location duration, workers and supervisors in charge. The asset information is automatically stored in the cloud system and transfer (through simple scan) to a barcode attached in the area of the task on the spot. Workers who are assigned to the activity confirm directly in the application prior to beginning, through the use of their smartphones or tablets, that they received appropriate safety training and that they have all personal protective equipment required. They also have to check and report the risks and hazards related to the activity. To stimulate the respect of the safety issues, supervisors are able to give positive or negative feedback to workers according to their performance. The C^4 mobile application proposed in this study makes it easier for officials and employees in charge of it, to maintain a simple and effective risk and quality assessment unified and built-in control real-time instances of forgetfulness and human errors, and therefore help reinforce the learning and internalizing awareness of safety risks and construction quality at work.

Figure 1. Activities and reports of the C^4 mobile application

5. System implementation and monitoring

The proposed system was tested on a construction site in Ramat Gan (Israel). The project is a residential building with a total of 34 floors above ground and with an average floor area of 550 sq.m. The total cost is estimated at 25. 8 million dollars and the duration is 3 years. The workforce is made up of 30 workers, with one main contractor and several subcontractors. This project represents one of the main challenges for the engineers because of the small plot of land where it is realized.

5.1. *Safety Indicators*

In this study safety performance indicator was defined in terms of worker's behavior. This because, the literature review has been demonstrated that unsafe behaviors of workers are directly related to safety problems. Observations (safety samplings) regarding worker's behaviors were conducted by the authors one round per week at the same days and hours. This to eliminate the effect of the daily and weekly variations of performance. At least four hundreds data points were collected at the site in each safety sampling. Forty observations were carried out at constant intervals of two minutes for a crew of formworkers, which includes between ten and twenty workers. Fixed interval technique is valid, dependable, considered credible by construction safety experts and it is particularly adaptable to the study of short-cycle, highly repetitive group operations [26]. Individual behavior was graded according to the following categories: "remarkable safe behavior", "safe behavior", "risks himself", "risks others" and "risks himself and others".

Performance score was generated at each safety sampling and the final score was assessed on two different aspects:

Safety Indicator 1 (S.I.1), which represents the quality of safety behaviors. It is calculated as showed in Eq. (1).

$$S.I.1 = \sum_{i=1}^{5} Pi \cdot Wi \tag{1}$$

Where, *Pi* is the percentage of the behavior detected for each category, and *Wi* is a correspondent weight assigned at each category, as follows: (1) remarkable safe behavior, (0.75) safe behavior, (0.5) risk himself, (0.25) risks others and (0) risk himself and others.

Safety Indicator 2 (S.I.2), which represents the percentage of safe activities. It is calculated through the division between the number of safe observations (marked under remarkable and safe behavior categories) and the total number of data collected, as similarly used in [3].

5.2. *Quality Indicator*

Number of reworks, in this case, (or/and the related additional cost and hours) could not be taken into account as a quality indicators because the analysis of the project diaries showed an under reporting of the performed reworks. In addition such measure of quality is not adequate to monitor the weekly variation of quality performance. Thus, the quality indicator was set up through direct in site observations. The quality indicator (Q.I.) used and developed in this study enables to evaluate the overall quality of the construction work. Q.I. is defined by a value between 0 and 100 which expresses the quality state of the reinforced concrete works performed. Its score is calculated every week through structured quality samplings.

In-depth investigations of three quality aspects of the performed reinforced concrete works were carried out: (1) the concrete works, (2) steel works and (3) formworks. In each of the above mentioned categories keys quality parameters were inspected and marked according to a five point rating scale. For example for the steel works, following parameters were observed: the adherence of the specifications (through the consultation of the blueprints), the concrete cover (through the control of its measure and the correct use of the spacers) and the correct installations of the rebars (through the control of the implementation and the ligature between them). For each parameter, the percentage of the correct work was recorded. Similar procedure was developed and implemented concrete and formworks. The final score of the Q.I. is calculated by the average of the score of the three categories. This indicator enables to evaluate the overall quality construction of the reinforced concrete works performed every week and to monitor its value over time.

5.3. *Monitoring of the Safety and Quality Performance*

The phases involved in monitoring the trend of the safety and quality performance, resulted from the implementation of the mobile C^4, were as follows:

Phase I. Baseline phase: it is the starting level of the safety and quality performance. It was identified through the first in-site surveys.

Phase II. Implementation phase: it is the phase, after the baseline phase, during which the C^4 application is working. Safety and quality observation were carried out along the implementation upon achievement of convergence of the findings.

6. Findings

This chapter describes the findings resulted from in-site observations performed by the research team during 11 weeks. These observations consist of 2 weeks of base-line phase, and 9 weeks of implementation phase. The average score of the Safety Indicators during the base-line phase were found to be extremely low as shown in Fig. 2. It was due to a limited involvement of the first and mid-line managers to the safety regulations. The main unsafe behaviors and activities detected during this phase were: (1) workers avoided the use PPE (Personal Protective Equipment) (2) unsafe load lifting (3) work in high position without a secure platform (4) climb the formwork and (5) throw objects between workers. Besides, site layout conditions were under low level of organization, in terms of safety of crossing, protection of falls, protection shaft, density, order and organization in general.

A significant improvement of safety performance was observed following the implementation of the application. The convergence of the score of the safety indices was achieved after 7 weeks of implementation. Fig. 3 shows the distribution of the worker's behaviors observed during the sampling performed in the second week (base-line phase), and Fig. 4 shows the distribution at the tenth week (implementation phase). Comparison shows the large decrease in unsafe behaviors (categories n.1, 2, 3) with the consequent increase of the safe behaviors (categories n.4, 5), especially the remarkable safe behavior category (category n.5). Furthermore, a drastic reduction of unsafe activities (90.8% less) was observed as shown by S.I.2 in Fig.1. Fig.5 shows the trend overtime of the Quality Indicator between the two phases. Main quality problems observed at the start were as follows: (1) widespread segregations, (2) widespread leakage of concrete, (3) concrete surfaces not uniform, (4) insufficient concrete cover, (5) poor rebar works, and (6) poor formwork's quality. As for the Safety Indicators, Quality Indicator improves significantly during the implementation phase until reaching the convergence of the results after 7 weeks.

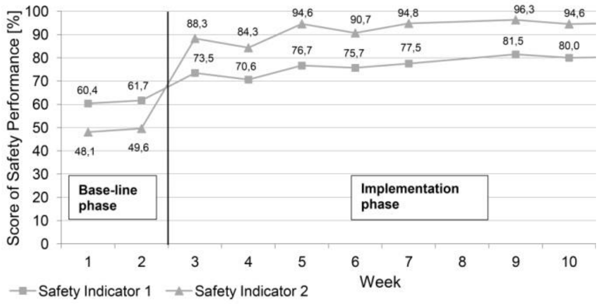

Figure 2. Trend of safety performance

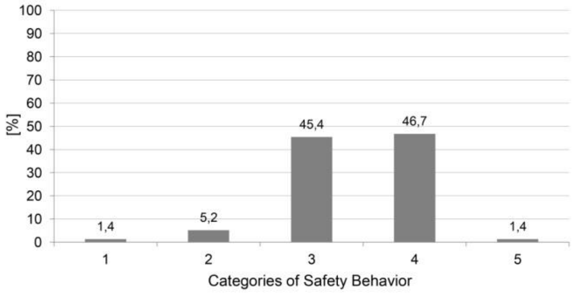

Figure 3. Distribution of safety behavior week n.2

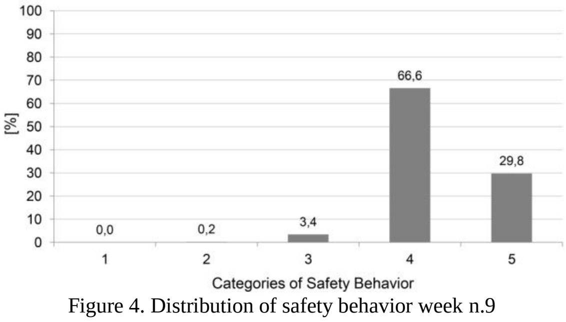

Figure 4. Distribution of safety behavior week n.9

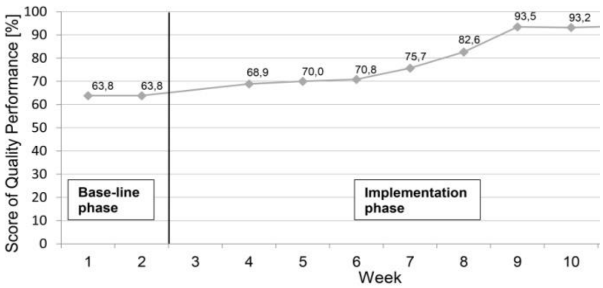

Figure 5.Trend of quality performance

A statistical analysis of the safety and quality key performance indicators, prior and after the implementation of the system, was carried out using the Student t-test. The differences of the safety and quality indicators between the two phases were found at level of significance of 99%. The study provides a clear evidence of the effectiveness and the benefits of the proposed system by stimulating site management involvement.

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Getting Fired Material with Vitreous Binder Using Frame Technology

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Abstract

There is no chance to expand kiln materials properties and scope as such materials do not have any coarse aggregate in their composition. In this regard, we decided to develop a fired material with coarse aggregate. It is only possible to add coarse aggregate in a material composition when we get unshrinkable binder that has strong adhesion to the aggregate grains. In this article, we describe a method for producing such a binder of waterglass and sodium-lime-silica glass powder during firing semifinished product. We propose to use frame technology for molding the semifinished product – the binder components are used sequentially with the gluing the frame of the coarse aggregate in the form of waterglass and impregnation of the extracted hardened frame with the glass powder suspension. The frame technology provides a large pore structure of the material and reduces the amount of binder. The impregnation of the hardened frame and the firing of the semifinished product performed at 740 - 780 ° C without molds. By using the proposed technology, we obtained the fired material with coarse aggregate on unshrinkable porous vitreous binder. Physical and mechanical characteristics of the material allow to use it for manufacturing of insulating or structural-insulating products for building purposes in the form of blocks or slabs.

Keywords: coarse aggregate, waterglass, soda-lime-silicate glass, roasting

1. Introduction

Ceramics is attractive as a building material because of its durability and eco-friendliness. The most available and massive raw material for ceramic building products is natural clay which has a heterogeneous composition. To correct the molding, drying and roasting properties of clay raw materials, they use different corrective additives, including fine aggregates, but coarse ones are used in a very limited way. Unlike the production of roasting-free binder materials, in which coarse aggregates are widely used as controllers of material properties and to reduce binder consumption. The reason for this lies primarily in increased shrinkage of the ceramic mass during the firing, preventing the formation of defect-free contact zone between a ceramic crock and a coarse aggregate. Studies related to the use of coarse aggregates in roasting materials follow the path of replacing the clay component with other eco-friendly fired binders, allowing us to create defect-free contact zone between binder and coarse aggregate [1-3].

Thereupon, as described in this paper, the results of research are very important as they aimed at developing technology for getting a fired material with a coarse heat-resistant aggregate and eco-friendly, vitreous and porous binder.

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2. Objective and Methods

The objective is to develop the fired porous vitreous binder and the technology for the production a material with a coarse heat-resistant filler based on this binder.

The methods for the research included: selection of the aggregate type and materials for fired porous vitreous binder, establishment of basic technological parameters of producing finished products using the frame molding technology.

We used expanded clay gravel as the filler.

For fired porous vitreous binder, we selected glass powder obtained by grinding utilized container and building glass and liquid sodium glass.

The choice of glass powder is due to the chemical activity and ion exchange properties of dispersed glass. These properties allow us to use it under certain conditions as a binder [4]. It is important to note that glass becomes pyroplastic when heated and is able to act as a high-temperature (calcining) binder.

Liquid sodium glass was selected as a source of alkali silicate solution as it is able to provide the flow of leaching and supplying with water of the glass powder initial structure [5, 6] during the semifinished product molding and drying. Liquid glass also performs the function of an adhesive for bonding the filler granules at a two-stage molding of semifinished product using the frame technology.

The two-stage molding of non-calcined materials with fillers includes preliminary bonding frame of the aggregate grains and then filling the voids of hardened frame with the binder (matrix composition) [7]. The difference between the proposed technology and the one described above is that after filling the voids of the hardened frame with the matrix composition, the binder is synthesized during the following drying and calcining the semifinished product. The frame molding technology was chosen to speed up the drying process of the semifinished product before firing. The degree of filling of the intergranular voids volume with the calcining binder leads to the obtaining solid or macroporous structure of the material. It should be noted that the possibility of obtaining large-pore material structure is an advantage of the frame molding technology compared to the concrete molding technology.

Theoretical justification of the synthesis mechanism of a two-component composition porous glassy binder is conducted on the analysis of modern conceptions about structure and properties of alkaline silicate solutions described in [5] and physico-chemical behaviour of alkali silicate glasses in contact with water, given in [6].

When drying liquid sodium glass, which sticks together frame, there are supersaturated metastable solution with the subsequent transition into the vitreous state of sodium silicate hydrate forms during moisture evaporation.

Solidification is accompanied by polymerizing silicon-containing chemical bonds when removing the hydroxyl-hydrogen groups and forming the three-dimensional polysilicon frame structure with cells of this type:

$$\begin{array}{ccccc} & | & & | & \\ - & Si & - O - & Si & - \\ & | & & | & \end{array}$$

The cured adhesive bond has a strong adhesion to the surface of the porous filler and high strength, but it is not water-resistant. During subsequent drying of the frame impregnated with an aqueous suspension of glass powder, there is a dissolution of vitreous liquid-glass bonds as the process of interaction with a layer of a glass suspension. The process of the hydrated sodium glass dissolution is accompanied by a transition to a solution of sodium cations due to solvation interaction. The kinetics of silicate dissolution is determined by the glass module and the temperature. Towards the sodium cations, water molecules diffuse in the glass phase, some of which enter the hydrolysis reaction with the anionic glass frame:

$$\equiv Si - O^- + H_2O \rightarrow \equiv Si - OH + OH^- .$$

Having high mobility, the formed hydroxyl ions leave the reaction zone at the interface and go into the solution. Released monomeric and polymeric anions (existing in the glass) can also go into solution. Cations have a higher transition speed in the solution than anions do. The consequence of this is the creation of conditions to increase the hydrated silica concentration at the interface. As the temperature rises during the processes of material drying and the pH lowering, there is polymerization of hydrated silica and the formation of the silica gel film. At a certain stage of drying, the formed viscous gel layers slow down the process of vitreous liquid-glass bonds dissolution of the frame, and it helps the frame to save certain strength and allows us drying the impregnated frame without molds. Simultaneously with the process of interaction between the glass mortar slurry and liquid-glass frame adhesive, there are processes of leaching and watering of the original structure of the glass particle suspension, which mechanism is based on the interaction between aqueous alkali solutions and alkali-silica. The glass watering goes together with hydration and hydrolysis and is accompanied by the adsorption of alkaline metals hydrated cations on the silica surface active areas that develop when grinding the glass. Further there is the depolymerization of silica due to the hydrolysis of bonds: $\equiv Si - O - Si \equiv$ along with the formation of silanolate groups $\equiv Si - OH$.

Hydrated silica when dried is transferred to the surface of glass particles. With an increase in its concentration in the drying process, the silicic acid polymerization takes place to form dense elastic gel film having astringent properties. As the removal of free water from the drying material, sodium hydrosilicates develop from the destruction products of the adhesive bond of the frame and the glass particles suspension. After drying, the remaining free water forms hydrogen bonds with the silanol water. Subsequent heating of the raw product in the kiln to 400 °C is accompanied by removal of water from sodium hydrosilicates. With further temperature increase to 740-780 °C silica bonds are destroyed, silicon-oxygen tetrahedra polymerized and the water is released while the dehydration of the hydroxyl glass cover. In the same temperature range, the eutectic mixture of Na_2O-CaO-SiO_2 system forms from the components of the complex binder and during melting, it provides the accumulation of significant amounts of melt with the necessary pyroplastic mobility and the closed pores formation in the calcining bond volume. In case of coincidence of the gassing and the closed pores formation processes, there are the conditions for the swelling of the binder with a sharp increase of vapor pressure in the pores.

3. Process description

The technology of obtaining material with the proposed calcining binder includes the following operations:

1. Mixing of the aggregate with liquid glass and the prepared mixture placing into molds.
2. Curing of vitreous binder frame in the molds during the drying process at temperatures of 60-80 °C and obtaining the frame.
3. Removing the hardened frame from the mold and impregnating it with an aqueous suspension of glass powder.
4. Drying impregnated frame at a temperature of 60-80 °C.
5. Calcining of the impregnated and dried frame at 740-780 °C.
6. Cooling of the calcined product inside the kiln.

The rheological characteristics of the binder at the calcining operating temperatures provide products resistance to deformation and preservation of regular geometric shape with some increase in volume, and it allows us to calcine products without special tooling, using a heat-resistant trays with a smooth surface.

The binder has a strong adhesion to the aggregate grain surface.

Obtained material can have a coarse or a monolithic structure depending on the degree of the frame pores filling with the binder during the products molding (see Fig. 1):

a b

Fig 1. Macroporous (a) and monolithic (b) structure material with expanded clay fraction 5-10 mm.

Physico-mechanical properties of the obtained samples of the large-pore structure are changed depending on the characteristics of the filler, on the degree of filling voids between the grains with the calcining bundle and are characterized by the following indicators: density of 600-846 kg / m^3; water absorption determined after boiling the samples in water for 30 minutes is 10,6-24,2%; the thermal conductivity of the sample (density of 730 kg / m^3) - 0.17 W / (m·°C); the compressive strength is 1.5 to 2.5 MPa.

The diameter of the pores of the calcined glassy bundle defined by microscopic examination is 0.02 to 0.50 mm.

4. Results and Analysis

The results showed that the swelling of the binder compensates its shrinkage during firing, which prevents the formation of shrinkage cracks during the interaction of the binder with the filler grains frame, leading to a sharp reduction of the material strength. The effect of eliminating shrinkage cracks during glassy binder swelling shown in Fig. 2.

To confirm the assumption that the vitreous binder intumescent agent is water vapor in pyroplastic state during calcination, we performed the infrared spectroscopic studies. In the IR binder absorption spectrum after drying the impregnated frame, we recorded a broad absorption band in the range of 3 300 – 3 600 cm^{-1} associated with O – H bond stretching vibrations in oxyhydryl groups O_mH_n [8], and the absorption band at 1446 cm^{-1} associated with the presence of carbonate ions. After firing the semi-finished product, the intensity of the absorption band of the calcining bundles (associated with stretching vibrations of the O – H bond) decreases and the carbonate ions absorption band is completely disappear. Thus, the presence of absorption in the 3300 - 3600 cm^{-1} in the calcining bundle indicates that the expanding agent is water vapor.

To establish the mechanism of pore development in the calcining binder we used thermogravimetric analysis with the TGA/DSC1 derivatograph. The binder samples for analysis were chosen from impregnated and dried at a temperature of 60-80 °C frame. Three parameters were automatically recorded: temperature rise (T), thermogravimetry ('ТГ' - weight loss of the sample), the rate of weight change ('ДТГ' - intensity of destruction), see Fig. 3. After the appropriate preparation, the sample was heated from 25 to 750 °C at a rate of 8 °C /min.

On the vitreous binder sample derivatogram (see Fig. 3a) in the temperature range from 625 to 720, at which the binder swelling occurs, we noted changes on 'ТГ' and 'ДТГ' curves that can be explained by the water removal from the watered structure of vitreous binder in the observed temperature range.

On liquid sodium glass sample derivatogram of (see Fig.3b) in the temperature rangecorresponding to the swelling of the binder, we did not observe any significant processes of degradation and decomposition of the sample (no steps on the 'ТГ' curve and peaks on the 'ДТГ' curve) associated with the evolution of gaseous reaction products. Analysis of the sodium-lime-silicate glass sample derivatogram showed similar results.

The results show that new formations are the source of the gaseous phase during the binder swelling. These new formations come from the interaction of water glass binder with particles of the impregnating glass suspension in the process of the material heat treatment.

a b

Fig. 2. Contact zone of the calcining bundle without swelling (a) and with swelling (b) of the vitreous binder.

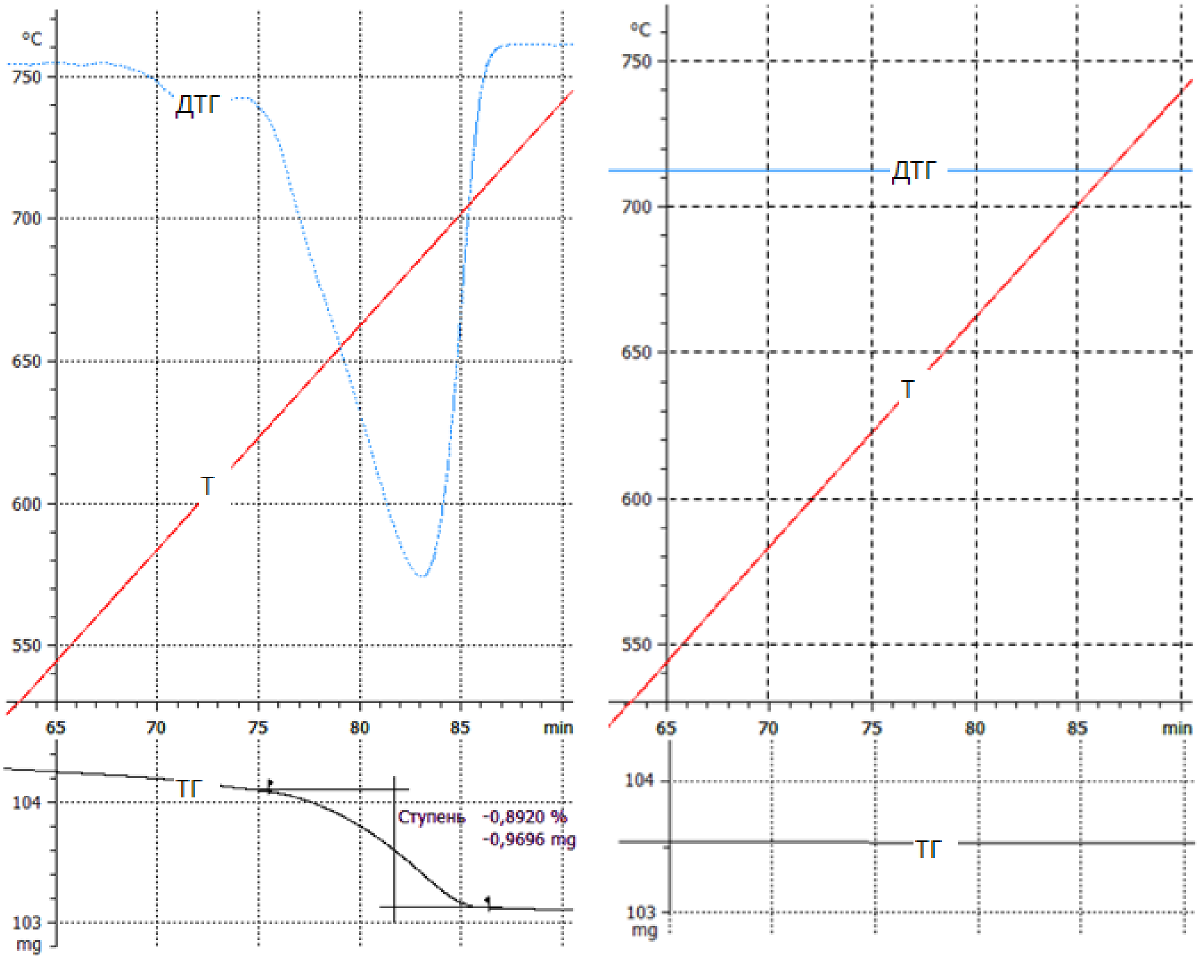

Fig. 3. Derivatograms of: vitreous binder (a), liquid sodium glass (b)

5. Conclusions

The results of these studies, having searching nature, prove the possibility of obtaining a calcined material with coarse aggregate on a calcining porous vitreous binder using frame technology. Swelling of the binder compensates its shrinkage during firing, it prevents the formation of shrinkage cracks during the interaction of the binder with a coarse aggregate rigid frame.

Rheological characteristics of the calcining binder of the developed material make it possible to calcine products without special molds, using only heat-resistant trays with smooth surface.

The obtained material has a water resistance, fire safety, environmental cleanliness. Physical and technical characteristics of the material make it possible to use it in construction as an insulating or structural-insulating construction material in the form of blocks or slabs.

The results obtained can be used for the development of industrial production of the developed material with in brick factories with the addition of supplementary process equipment.

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Classification of "I" – Shaped Glass Columns

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Abstract

The application of glass as a modern material in construction field is highly desirable in comparison with other materials such as wood, steel or the reinforced concrete due to aesthetic purposes. Hence there is a high demand of official standards that meet the industry requirements. Glass recommendations which define the function of the materials as a load bearing element are not available as other conventional materials but only some references in the literature. In the last years the properties of glass and the interlayer foil developed at a high rate. This development is not typical if we compare it conventional building materials. However, the glass designing demands are more sensitive in material and safety as well as in comparison with the other materials. Therefore, load bearing capacity, durability and the individual properties of glass must be examined in parallel sequence. More than 120 scaled-size specimens were loaded under compression to study the buckling behavior of glass columns with plane shaped cross-section at the BME, Department of Construction Materials and Technologies. During the tests, loading behavior and properties of the columns were under examination and analysis. The measured and calculated critical buckling forces, maximum forces and strengths were analyzed in function of slenderness. The glass specimens were classified into different groups based on the experimental results because classification is a primary issue at the designing phase. Authors provide aspects to the classification in the present article. Planeness of some specimens were measured to take into account their initial geometric imperfections for the classification. The rollers affect the shape of the glass table during the heat strengthening because waves are formed on the glass at the solidification moment of glass.

Keywords: Buckling; columns; glass; glass planeness; stability

1. Introduction

It is unnecessary to emphasize the role of glass as load bearing elements in buildings. Glass must possess design standards as other construction materials. Although standards cannot cover the glass designing at the international level. Even less information are available for the topic of buckling of glass. Therefore, this subject has to be under investigation in order to ameliorate the safety and reduce the risk of danger. Nowadays several researchers in many countries examine the buckling of glass columns in case of different cross-section. The authors wanted to investigate the base of the buckling phenomenon and the behavior of the glass columns, hence more than 120 plate glass specimens were loaded under compression by concentrated load at the laboratory of Department of Construction Materials and Technologies, BME.

In case of different glass types, the dependency of ULS and SLS of glass columns on the buckling type was investigated in the present article. The own shape distortions influence highly the stability behavior. The different glass processing methods (e.g. heat strengthening, lamination) also have an impact on the own shape. Instead of the existing distortion measurement methods, a new method had to be introduced which was applied in this research. The measured results justified the mentioned effects.

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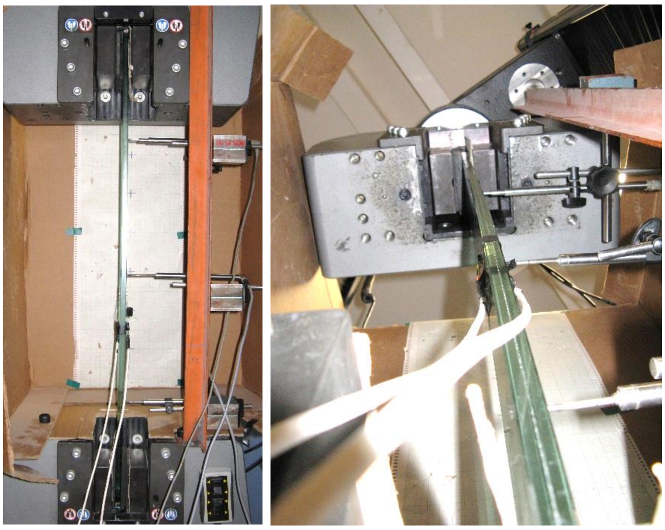
2. Test parameters and test set-up

Laboratory experiments were carried out in order to study the buckling behavior of single and laminated glass columns. Specimens were examined with the application of Instron 5989 testing machine. The scales of the geometry of specimens (height, thickness, width) were selected based on existing glass columns from international and Hungarian realized projects. Test parameters of glass specimens were selected as the following: Constants: test arrangement; support type; glass width (80 mm); interlayer material (EVA foil with thickness of 0.38 mm); edgework with polished edges; temperature (+23 ± 5 °C). Variables: type of glass layers: heat strengthened glass (HSG) / non heat-treated float glass (annealed glass); height of specimens: 1000 mm; 920 mm; 840 mm; number of glass layers and the thickness of specimens: single layer: 8 mm; 12 mm 19 mm, laminated: 4.4 mm; 6.6 mm; 8.4 mm, 8.8 mm, 10.10 mm, laminated: 4.4.4 mm; The rate of loading: 0.5 mm/min; 1 mm/min. Support: Height of fixing: 95 mm; rubber plate (Shore A 80) was used between the steel supports and the glass. Simplified designations are used to distinguish between the studied specimens, these are e.g. H_2(4.4)_2_920_0.5: ~ H, F: Type of glass: H – HSG; F – non heat-treated float glass; 2(4.4): Number of glass layers ex.: 4.4 mm laminated glass; 2: The number of specimen; 920: Nominate height of specimen [mm]; 0.5: Rate of loading [mm/min]. Abbreviations were used for the float laminated glass VG and for heat-strengthened laminated glass VSG. Although laminated glass with PVB interlayer foil and fully tempered glass (FTG) were not the part of the test parameters, a few pieces of these were tested as well [1].

The load and vertical displacement of the upper cross-head of the Instron 5989 universal testing machine were continuously measured. At three different heights the buckling displacement (horizontal displacement) of all specimens were continuously measured with HBM displacement transducers during the tests. Strains at center point on the surface of the glass panels were measured with HBM LY11-10/120 strain gauges. At least three specimens were tested at each testing combination. Laminated specimens were loaded until all glass layers were fractured (Figure 1-2.)

Figure 1-2. The laboratory test set-up.



3. Experimental results

3.1. *Determined stages in the loading behavior*

Characteristic curves are presented as loading force vs. displacement (vertical, horizontal and deformations) diagrams to study the laboratory experimental results. Curves are categorized in three separate groups according to the numerous experimental results. Variation can be noticed in case of loading force vs. horizontal displacement diagrams. The characterization of the specimens depends on the stages of the loading history of the specimens. The name of stages are [2,3]:

- First stable stage
- Unstable stage
- Second stable stage

3.2. *Grouping of the glass specimens*

The *first group* contains all of the previously mentioned stages and in this group were experienced the highest critical bucking forces when compared to the other groups results. Force reduction can be observed on the vertical displacement diagrams in the buckling moment. Specific buckling point cannot be determined in case of the *second group,* the unstable stage disappears and after a stable section, the buckling is gradual. Only one stable stage can be observed in case of the *third group,* so the ultimate force can be determined, but not the critical buckling force [4].

The results of the specimens had to be distinguished depending on the groups of buckling at the comparison of the influence of the variables. All of three type of buckling can easily occur at one testing combination (one type of glass specimen). Despite the fact that different buckling types and different critical buckling forces are experienced at one testing combination, ultimate forces are equal as shown in Figure 3. The HSG can reach higher horizontal displacements and higher ultimate forces than the annealed glasses. However, the critical buckling forces of annealed and HSG scatter in the same range. The ranges are different for each testing combination. It also demonstrates that the ultimate limit state depends rather on the glass surface defects and on the glass strength, which can be increased by the heat strengthening. Furthermore, the critical buckling force depends rather on the imperfections. These experimental results mean that the type of buckling does not influence significantly the value of the ultimate force.

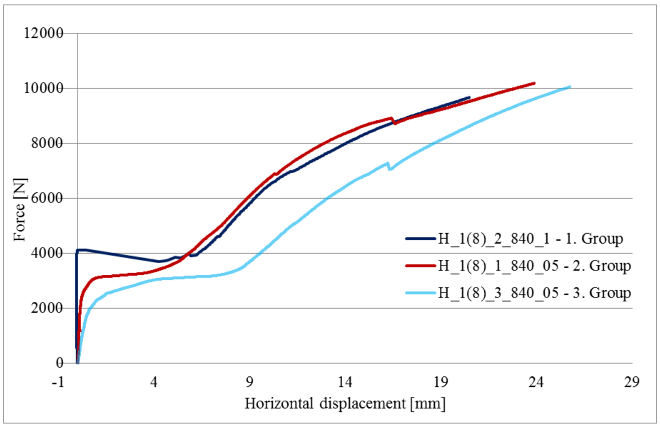


Figure 3. Loading histories of glasses which belong to one testing combination.

The average ultimate force results of the different groups are closely to each other. In Table 1. can be seen the average ultimate force quotients in percentage, which is obtained by the dividing the average ultimate force of a group by another. The standard deviation is below than 10 % in case of ultimate forces, but this value is over than 10 % in case of the critical buckling force due to the different buckling types.

Table 1. The comparison of the average ultimate forces (Fmax) of the groups.

The numbers of compared groups	Quotient [%]	Standard deviation [%]
1 – 2.	101,47	7,94
2 – 3.	97,28	5,66
1 – 3.	97,20	9,07

The difference between the critical buckling and ultimate force is lower in case of the *first group*; it is more significant in case of the *second group* as shown in Table 2. The situation is similar in case of the single layered glass or annealed glass because the difference on average is lower between the critical buckling and ultimate forces than the laminated and HSG.

Table 2. Comparison of the ultimate force (F_{max}) and the critical buckling force (N_{cr}) per groups.

	N_{cr}/F_{max} at the *1. group* [%]		N_{cr}/F_{max} at the *2. group* [%]	
The layering	Single layer	Bilayer	Single layer	Bilayer
Annealed glass	57	94	32	45
HSG	45	77	25	31

4. The distortion measurement

4.1. *Standards and previous measurements*

The distortion of glass influences heavily the stability and load bearing capacity of the load bearing elements. The influencing distortions are the overall bow, roller wave distortion, edge lift or twisted initial imperfection according to the standard EN 1863-1 [5]. This standard does not recommend definitely adequate measurement methodology. For instance, the measurement of roller wave is the following: use a straight edge and place it at right angles to the roller wave and bridging from peak to peak of the wave. However, this measurement does not provide continuous information about the shape of the specimen. This methodology seems simple and inaccurate. The own shape initial imperfections need more information about the shape to take into account at the calculation of buckling. The shape of glass surface was measured by international researchers as well [6]. They applied the previous method and a continuous lineside methodology. The linear error meant the own shape of the auxiliary line structure, hence a displacement transducer was applied perpendicular to the surface, and it was moved along the glass.

4.2. *New measurement methodology*

In our measurement methodology, the glass was fixed and the Wenzel LH 108 3D Coordinate Measuring Machine was moving above of the glass. The glass lied one of its side on the machine. The Metrosoft CM software was applied and micrometer was measured in high accuracy. Reference Point System was the most accurate method for the measurement. The measurement methodology was the following: Three points were chosen from the four corner points on the surface area of the glass. These points were base points of the measurement and they determine a plane. The different distance between the determined plane and the fourth point was divided between the 4 corner points, so a new plane was determined, in which is an average plane according to the four corner points it is called bestfit method. Three additional different base points were added in the two other axis: two points were perpendicular to the longitudinal axis and one parallel to the longitudinal axis. These points were needed to place the glass in three dimension. The machine measured the glass waves perpendicular to the surface. The own shape, twisting and the other distortions were determined with the application of this measurement. The measured points were placed in three different lines, two lines were placed 15 mm from the edges in longitudinal direction. The third line was in the middle of the specimen. The measured points were placed 15 mm from each other in one line. The application of closer measuring point system does not increase the accuracy of the measuring only the measuring time. Three measured lines were applied in case of the 80 mm wide specimens and five in case of 1200 mm long and 360 mm wide specimens.

5. The distortion results

5.1. *Basic notifications of the measurement results*

The twisting of glass was easy to determine in the application of this methodology. However, the difference of the first measured value per lines and the other members of each measurement line have to be analyzed for the overall bow determination. Roller waves are in this methodology the depth between two adjacent waves, which can be also easily determined.

Surface imperfections were measured in vertical direction. It means that the glass specimens lied on side. Hence, the effect of the shoulders, where the glass touched the plane surface of the machine, ought to appear in the measurement. This error does not clearly appear, therefore the measurement data contain them.

The effects of the interlayer foil, the laminating procedure (PVB, EVA) and the tempering were studied on the initial imperfections in case of the 1200 mm long and 360 mm wide specimens. However, the results of these glasses were not suitable to analyze the buckling phenomenon of the glass. Although the 80 mm wide specimens were compressed by centrally load after the distortion measurement. The distortion of the specimens was examined by inspection before the loading. Higher overall bow and roller waves could be determined and in certain cases where the direction of the buckling was predictable. Nevertheless, the distortion, that is noticeable by inspection, means significant imperfections. The latter can influence heavily the critical buckling force of the specimen.

5.2. *Distortion results of the 1200 mm long 360 mm wide specimens*

The maximal measured values of float 12 mm thick single layer glass and laminated glass, consisted of two 6 mm thick glass layers, were below 0,2 mm. The maximal measured value of the other glasses (the laminated float glass consisted of three 4 mm thick glass layers and the other fully tempered single and laminated glasses) were between 0,1-0,6 mm as shown in Table 3. The results of laminated FTG were the largest during the whole testing. The distortion of the annealed glass was even smooth and no visualization of regular curves in the diagrams. The diagrams are rather curved and the roller waves can be observed in case of FTG. The displacements of roller waves are comparable with the distribution of rollers in the heat strengthened furnace where the displacement of the rollers is 125 mm. The value of the overall bow of FTG also stepped to a higher level. Not only small waves were experienced in the results but there were higher waves between more rollers as well. These waves could influence the whole shape of the glass. The highest roller wave depth was 0,077 mm in case of FTG. This value is 0,053 mm was in case of HSG. However, there were smaller waves in case of annealed glass with 0,02 mm depth despite the fact that the float glass was not heat treated. These waves can be formed when the float glass is still not enough solid and already is pulled from the melted tin to the rollers, where it will solidify. These statements must be confirmed by further measurements.

Table 3. Maximal value of the distortion measurement results.

Type of glass	Overall bow [mm]	Roller wave [mm]
Single layer float glass	0,15	0,02
Laminated float glass with PVB foil	0,07	0,002
Laminated float glass with EVA foil	0,2	0,02
Single layer FTG	0,35	0,03
Laminated FTG with EVA foil	0,6	0,077

5.3. *Distortions and own shapes of measured specimens*

In Figure 4. and 5., the distortion measuring results can be seen. Both sides of float and heat strengthened laminated glass, consisted of two 4 mm thick glass layers are drawn. The overall thickness is 8.02 mm and the measured surface is marked with blue color. Normal differences cannot be distinguished from the ideal surface hence the differences were magnified 20 times signed by red color. The surfaces are approximately parallel in case of all type of specimens. Differences can be determined at the end of specimens in case of laminated glasses, where the laminating procedure causes that the surfaces are closing due to the air suction. The detected waves in shorter or longer displacements on one side can be compared with the other side waves. The diagrams clearly illustrate that the convexity of the waves located in the same position (adjacent) are the same except the end waves. The radius of the curves is also similar in same position. Before laminating these glasses had with major probability different own shapes, after the lamination they had definitely one common shape. The overall bow can be seen in case of float glass, which has the major responsibility for the direction of the buckling.

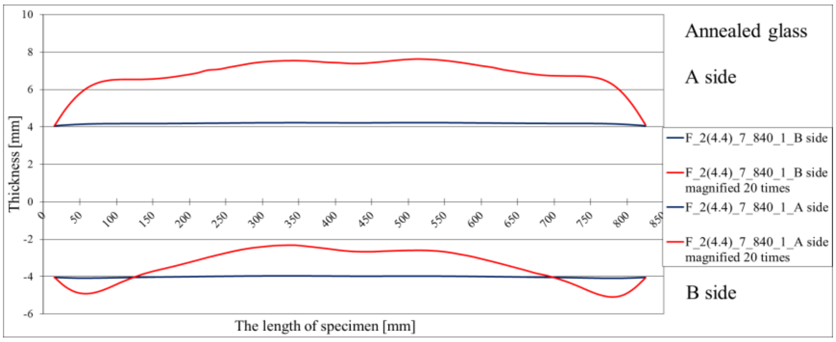


Figure 4. Distortion measurement results in case of annealed laminated glass.

The overall bow was the least in case of the laminated glass consisted PVB interlayer foil, in one case the maximum measured value was less than 8 micrometers which was equal with the sign of the permanent marker. The knowledge of the own shape makes estimable the calculation. The roller waves can increase the critical buckling force in certain cases.

The authors are planning to measure the distortion in case of new specimens with this new methodology and to study the influences of the distortion for the buckling capacity and phenomenon because a lot of new information were determined from this few measurement and it seems much more reliable and accurate than the earlier type of measurement methodology.

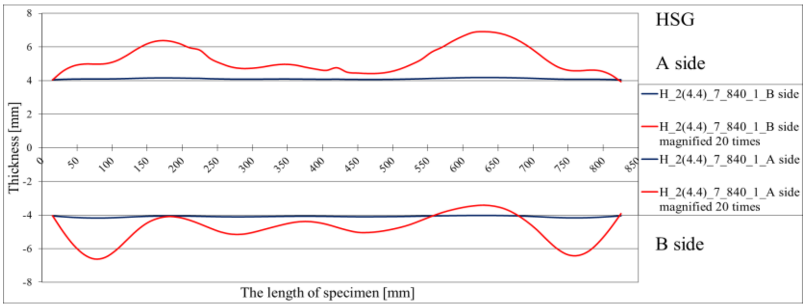


Figure 5. Distortion measurement results in case of heat strengthened laminated glass.

6. Conclusions

In this paper, significant results were demonstrated in the aspect of the “I”-shaped glass columns designing. The type of buckling does not influence significantly the ultimate force. The standard deviation of the critical buckling force is above than 10 %, however it is less than 10 % in case of ultimate force. Therefore, the ultimate force can be calculated independently of the type of buckling. In the future, the authors have to determine and apply designing factors in the calculation formulas of critical buckling force to make the designing more accurate and safe. In case of the first group, the critical buckling forces occurred at higher loading force than the second group depending on the glass types. Concerning the design, the results indicates that the efficiency of the load bearing capacity is better in case of the first group, however designing for the critical bucking forces of second group is safer.

A new distortion measurement methodology was demonstrated. The maximal values of overall bow and the roller wave depth were presented in case of different glass types. It is stated that the lamination method and the heat strengthening can increase mostly the measured values of distortions. The roller wave can increase the buckling resistance in particular case, when the curvature of the local distortion is opposite of the whole buckling direction, the overall bow will decrease the SLS. The measured sinus wave depths were 10 times lower than the overall bow based on the new distortion measurement method. It is necessary to incorporate more realistic own shape of the structural element into the calculation formulas.

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Exploring a Simple Visualization Tool for Improving Conceptual Understanding of Classical Beam Theory

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Abstract

First year students struggle to understand the concepts in introductory engineering physics courses. Computer generated visualizations have proven their value for improving learning in tertiary education. However, it remains often unclear how visualization software can be effectively deployed in classrooms to best improve learning outcomes. In this paper we put a freshly developed educational software entitled “The virtual beam demonstrator” to a first test in a physics and mechanics lecture at Oslo University College. The intention of this work was to explore how to get the balance between technology, pedagogics, and content knowledge right to best support student learning. We evaluated student learning outcomes of our initial attempt to use the software in a classroom based on a student evaluation form. While initial results are promising, we cannot claim to have significantly improved student learning in our initial attempt at using the software. The evaluations showed only slight improvement in conceptual understanding by the students. This finding was not unexpected as we anticipated that finding the right approach for putting this software to use would take several attempts. To turn failure into success, we would need a stronger emphasis on customized pedagogic methods. Relevant theory is explored and an approach based on “Interactive Lecture Demonstrations” is proposed.

Keywords: classical beam theory, visualization, coherence, engineering education, interactive lecture demonstrations

1. Introduction

Several studies in the past three decades have shown that traditional lectures (“chalk and talk”, “teaching by telling”, “deductive” as opposed to “inductive” [15]) are not the best way of improving students’ conceptual understanding within engineering education. Sokoloff and Thornton claim to see no more then 5-15% learning improvements after a physics course run exclusively based on traditional lectures [1]. Similarly, a large longitudinal 10-year study (1999-2009) run at the University of Sydney showed an improvement of 13-19% in students’ conceptual understanding after a 5-week introduction physics course (Newton’s laws, velocity and acceleration) lectured in a traditional manner [13]. Inspired by such research outcomes, Sokoloff and Thornton developed a novel pedagogical approach called «Interactive lecture demonstrations» [1]. Their pedagogical approach is designed to encourage discussion, reflection and understanding. In consecutive studies they report up to 80% improvement in conceptual understanding from courses where this approach is implemented [13]. Some of the findings from these studies suggest that student learning can be significantly improved when emphasizing conceptual understanding by making use of appropriate technology [14].

Although a range of such teaching concepts are available, civil engineering courses are still typically lectured in a more traditional manner. Consequently, many first year engineering students find it difficult to obtain conceptual understanding from what is presented on the blackboard alone. Laboratory work is the typical solution to this problem. However, increasing class sizes limit the use of practical lab work in basic physics courses. In this paper, we contribute to the discussion of how virtual demonstrations of physical concepts and principles could contribute to increasing learning outcomes in civil engineering. At last year’s Creative Construction Conference, we presented an article introducing an early prototype of a software developed for the purpose of providing first year engineering students with an initial understanding of classical beam theory [2, 3]. The software features a three-dimensional view of different beam structures and their response to applied forces (e.g. deflection, bending moments, shear forces, stresses). It emphasizes visualization and ease of use to ensure that the system

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can be readily used in classroom settings. Following up on an initial test by ten first year students at Oslo University College in 2014, the software has been refined throughout 2015. This article picks up where its predecessor left off and we report our experiences from the first practical implementation of the system in a lecture on “Physics and Mechanics” at Oslo University College held in early October 2015 with more than 90 engineering students attending. The research question asked was: *How can the ‘Virtual beam demonstrator’ be used best in a lecture hall to support students’ conceptual understanding of classical beam theory?*

We argue that this research is important beyond the context of Oslo University College and that lecturers elsewhere may find useful ideas for teaching their students based on our work. We made the software freely available on the web (http://www.mathworks.com/matlabcentral/fileexchange/49780-virtual-beam-demonstrator) and the two versions (e.g. 1.0 and 2.0) have been downloaded altogether more than 100 times indicating interest in our work. To understand how to best use the software in a classroom setting we ingrained our work in the Technology, Pedagogy and Content Knowledge (TPACK) framework stemming from the literature on pedagogics [12]. This framework has been developed to explore how technology can be utilized to its full potential within education. The remainder of the article is structured as follows: first we introduce the TPACK theory informing our work, second the method is briefly presented, third the findings of the student evaluations are presented. Last, the discussion and conclusions of our work are introduced.

2. Theoretical lens

Duval makes an important distinction between vision and visualization [7]. Vision is the knowledge we achieve through direct access to a physical object. Visualization on the other hand, is about comprehension of the invisible – some kind of link between the physical and cognitive. In classical beam theory there is an obvious visual link between load and deformation. The eye observes that the beam deflects when a load is applied. This is however not the case for the interrelation between load and bending moments, shear forces and stresses. These are not visible (although stresses could be measured with sensors) and therefore often perceived as theoretical and complicated by students. This paper argues that visualization could contribute to make these interrelations clearer. The complicated theory is integrated into something practical to create what is called coherence.

Comprehensibility, manageability and meaningfulness are central concepts within the theory of coherence [8]. When students are introduced to new material, they should ideally understand it, believe in their own ability to manage it and find it meaningful. This can be obtained with support from the students’ own previous knowledge and experience, the education program and/or future professional experience [9]. Due to social and demographic reasons, engineering students seem to have less relevant practical experience than earlier. Fewer students grow up in the countryside with practical tasks as natural daily activities, their parents are typically not in practical jobs, practical activities in their homes are outsourced (fix the car, refurbish the kitchen etc.). In addition, there is no longer any practice requirements in the engineering education. Hence, it is probably more important than ever that the students find relevance within their study program.

Traditionally, laboratory work is where the students get practical experience within the engineering education. Civil engineering students are shown how concrete and steel beams behave when exposed to a load, mechanical engineering students see how different machines work etc. However, there is rarely any laboratory work in the theoretical first year courses like mathematics and physics where relevance is probably most difficult to spot for the students. In addition, the ongoing trend with stronger emphasis on research and fewer educators with both academic and professional background probably leads to an increased gap between education and profession [10].

According to the above discussions, we are possibly then in a situation where both teacher and student lack practical experience. The challenge for the educational institution is then to close the gap through pedagogical methods. Lee Shulman argues that content knowledge and general pedagogical knowledge must be integrated in order to achieve what he calls «pedagogical content knowledge» (PCK) [11]. By this he means that pedagogic strategies are not universal, therefore they must be adjusted to each individual problem or subject matter. Simple theory could possibly be efficiently presented on a blackboard, while more complex problems might need more active involvement of the students in order to be fully understood. An extension of Shulmans theory was introduced by Koehler and Mishra, who argue that technology knowledge also must be integrated into the pedagogical strategies [12].

TPCK or later TPACK stands for “Technology, Pedagogy and Content Knowledge” [12]. In a wider definition, technology could also be something like a pencil or a piece of chalk. In this context however, we consider modern digital technology. Technology is not utilized to its full potential within education today for several reasons: educators tend to replicate teaching methods from their own studies, many lecturers do not feel they master the technology well enough, and it can sometimes be difficult to see the added value in student learning. In addition, lecturers are rarely trained in relevant use of technology. The model presented by Kohler and Mishra consists of three fundamental knowledge components necessary for good teaching. Knowledge about content, pedagogy and technology. Each component is influenced by the other two. New technology could change a course content (why memorize historic dates when it is all on the internet?) or facilitate for new educational methods (flipped classroom). Pedagogic knowledge could affect a course content (enables us to communicate complicated theory we otherwise could not). According to the authors of the article, the best conditions for learning arises when all three components are integrated and customized to the individual teaching situation.

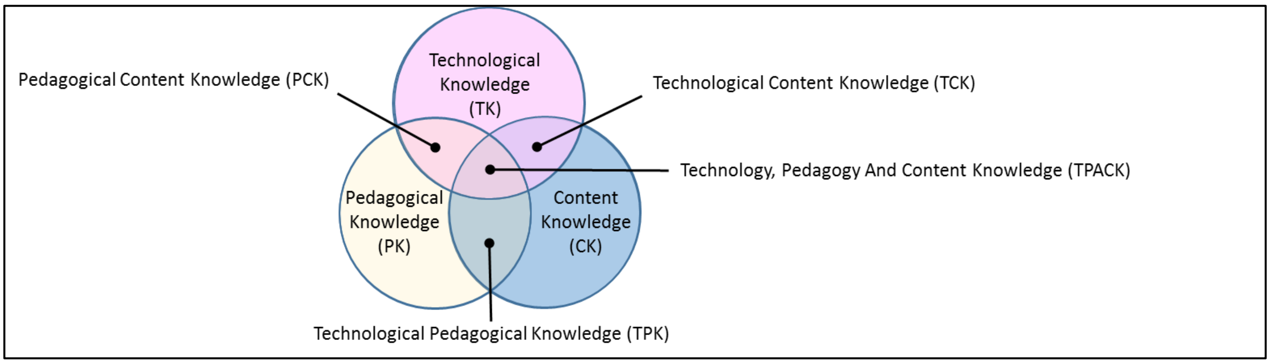

Figure 5: The TPACK framework and its knowledge components [12]

The interaction between technology and pedagogy (TPK) is especially challenging since there is not much software developed for education. Commercial software is designed to solve commercial problems. Within civil engineering there are several programs designing all kinds of load bearing structures. You enter the input (loads, geometries and other essential parameters) and receive more or less finalized drawings ready to be sent to the producer. Within education however, we are interested in seeing what happens between input and output. Which physical effects determine the design of the structure? «TPK requires a forward-looking, creative, and open-minded seeking of technology use, not for its own sake but for the sake of advancing student learning and understanding» [12].

3. Methodology

The software was introduced in a 45 minute lecture in the course “Physics and Mechanics” in early October 2015 with approximately 90 students present where the objective was to evaluate the benefit of the visualizations in a lecture situation. The lecture was held as a traditional “teaching by telling” session where the software acted as a more sophisticated replacement for the sketches and drawings that would have accompanied the theory otherwise. To assess student learning outcomes a questionnaire was prepared in which the students could rank their learning outcomes. This questionnaire was circulated after class. In addition to the questionnaire the student learning was tested based on two tests, one circulated before class and the second after class. The students had to calculate several different examples covering the content delivered in the lecture. The tests were similar, but the last one required a somewhat deeper understanding of the theory, to be expected after the class. The design of the questionnaire and tests was guided by what Bloom suggested to be a taxonomy for learning in higher education. In the 1950s Bloom described six categories of cognitive skills relevant to higher education [4]. These are knowledge, comprehension, application, analysis, synthesis, and evaluation, where the last 3 are known as the higher-level thinking skills. Learning outcomes in higher education (knowledge, skills, competence) are typically designed to cover all these levels. In many engineering courses however, the lectures, assignments and exams focus on reaching only the application level [5]. Students might even leapfrog the comprehension level as they experience that knowledge and application skills could be sufficient to pass the often calculation-packed exams. In a basic course like “Physics and Mechanics”, reaching the analysis level would probably be an appropriate goal and a good base for reaching level 5 and 6 in design courses later in the bachelor program. It must be ensured however, that the students have obtained sufficient comprehension of the material. The lecturer has the main responsibility for giving students the possibility of reaching higher-level thinking skills. Abstract theory presented in the traditional manner often causes apathy among students, while connecting it to something real and physical typically leads to more interest and enthusiasm. Visualization tools can contribute to avoid such information overload [6]. Using self-assessment and tests in combination works well for establishing how well the students learned the content. The other two dimensions important in TPACK, namely pedagogics and technology, were assessed based on observation.

4. Analysis

We arranged the analysis part based on TPACK. Figure 2 provides a visual impression of the software used, the classroom situation, and the content knowledge focused.

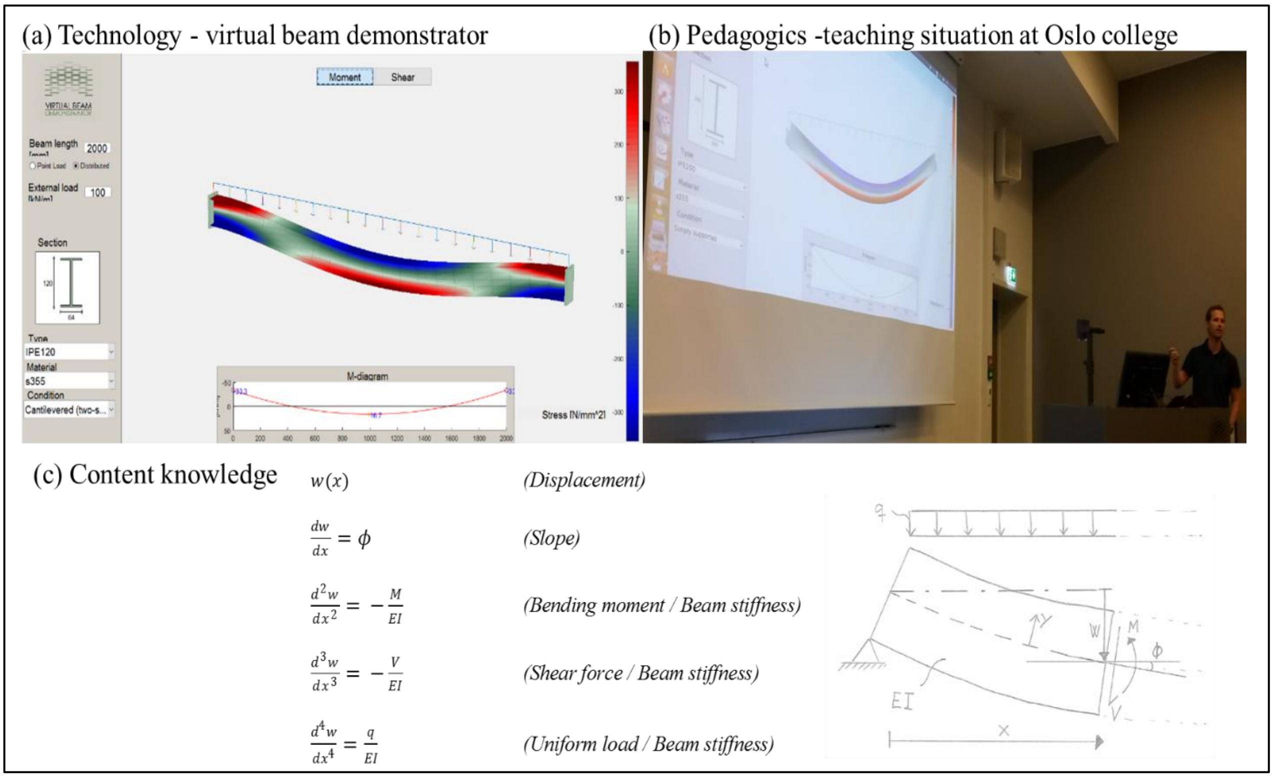

Figure 2: Virtual Beam Demonstrator 2.0 – technology (a), pedagogics (b), and content knowledge (c)

Content knowledge - The equations from the classical beam theory were programmed with MATLAB to visualize the different effects on a beam exposed to a load. The classical beam theory describes the interrelations between load (q), bending moments (M), shear forces (V), displacement (w) and slope (Φ) in a point (x) of a beam with given support conditions, length (L), section geometry (I) and material (E) [3]. From the bending moments and the shear forces, the bending stresses (σ) and the shear stresses (τ) can be derived at any point (y) of the cross section. An evaluation form was handed out to the students after the lecture. The students were asked to rank four different learning outcomes from the lecture. The results are shown in table 1. The students were also asked if they would like to see more use of similar software in lectures. This was scored with an average of 3,9 on a scale from 1 to 5. Added comments at the bottom of the form were mainly directed towards the following two categories: (1) the level of difficulty of the problem displayed was too high / we lacked basic understanding prior to the lecture (2) The deployment of the visualization in the lecture was too short to influence understanding.

Table 1. Student evaluations

To what degree did this lecture improve your understanding of:	Mean value
Bending moment and shear force diagrams for different constructions	3,5
The interrelation between bending moments and shear forces	3,5
The interrelation between bending moments and normal stresses	2,8
The interrelation between shear forces and shear stresses	2,9

1 = very low degree, 2 = low degree, 3 = some degree, 4 = high degree, 5 = very high degree

We ran two tests to assess whether the learning outcome was improved from using the software, one before and one after class. The tests consisted of several questions comparable in difficulty. The results of the test before and after class are presented in figure 3 below. The findings of comparing the test scores of the before and after tests show how student content knowledge has not significantly increased by deploying the system in class.

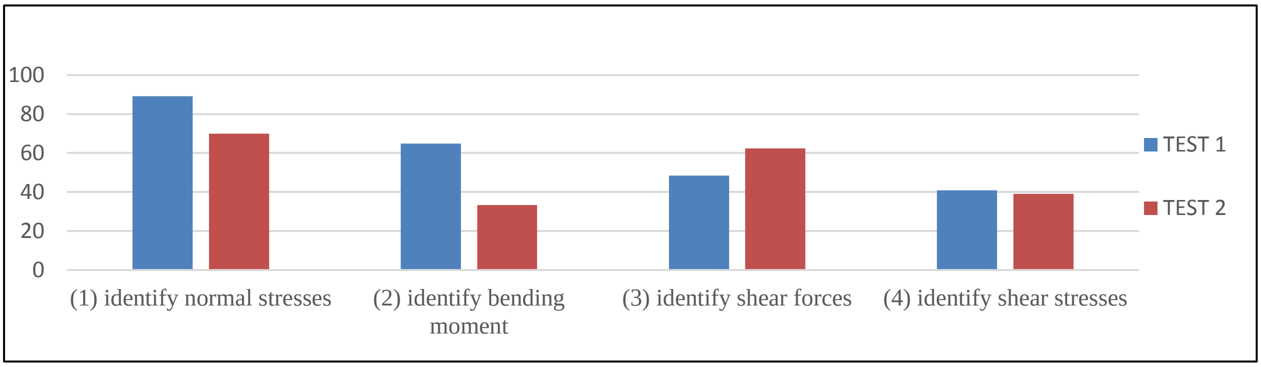

Figure 3. Test results before (test 1) and after (test 2) using the virtual beam demonstrator

Technological knowledge - The software was developed in 2014 by an engineering student at Oslo University College as part of his thesis work. An early beta version of the system was then assessed by ten first class engineering students. The suggested changes were then implemented in the system before deploying it in the classroom. One of the main advantages of the software is its simplicity. As soon as the properties section on the left (see fig 2) is completed (beam length, load, cross section, material and support conditions), a 3D model showing deformations and stress distribution appears along with a diagram underneath. The user may switch between two windows, moment (bending stress distribution and bending moment diagram, see fig 2) or shear (shear stress distribution and shear force diagram). The user may also rotate the 3D model in order to investigate it from other angles. This allows for interactive exploration, as appreciated by the initial test group [2]. Thus, the software can be said to be 'good enough' for achieving the desired goal for improved learning. However, the present version did not allow for being displayed on mobile devices which may have improved its utility for teaching.

Pedagogical knowledge- The students present in the experiment lecture had already been introduced to classical beam theory in previous lectures so no general introduction was given in the session. The starting point of the experiment lecture was a fixed cross section of a given material that was used in different beam setups. The idea was then to show how variations in support conditions, span width and load would cause changes in displacement, slope, bending moment, shear forces, and stresses. Finally, we would try to tie those findings to the general theory, e.g. through showing that bending moments are proportional to the first derivative (change) of slope or that shear force equals the first derivative of bending moments. These explanations were shown on a piece of paper using a document camera connected to a second screen. Most engineering students are visual, sensing, inductive and active learners [15]. This particular lecture was organized with both visual and verbal presentations of the material. However, the students were mostly passive observers, not given the opportunity to learn through active involvement.

5. Discussion

Based on the student evaluations we cannot conclude that the lecture using the visualization software improved conceptual understanding compared to a traditional lecture. However, the lecture was in fact held as a traditional "teaching by telling" session where the software acted as a more sophisticated replacement for the sketches and drawings that would have accompanied the theory otherwise. Based on the initial testing it can be claimed that the technology itself can be considered sufficient for teaching beam theory.

The analysis in this article shows that the pedagogical approach applied was unsuited for attaining the desired results of improved student learning. This could however be expected since this was the first time the system was implemented in a classroom setting. Based on TPACK we argue that the technological knowledge and content knowledge required for creating a successful classroom were in place. What we fell short on was pedagogical knowledge. This is where our teaching approach would need refinement. An attempt to visually express what happened in our classroom, explaining why student learning has not significantly improved, is depicted in figure 4. TPACK is a framework and not a fixed solution. An example of adaptation can be found in in a study by Hjelseth [16] about integrated building information modelling (BIM) in existing curriculum. The intersection of the aspects in TPACK was representing defined deliverables in the learning outcome.

Taking this technology further to become a classroom success would require a less traditional approach to classroom teaching.

This could be done based on pedagogical concepts like "interactive lecture demonstrations". Instead of the physical experiments recommended by Sokoloff and Thornton, the software could be adjusted to execute virtual experiments as a starting point for active learning lectures. This would require less equipment and would also enable us to visualize more aspects of the classical beam theory than a physical experiment. Thus, the next step in developing this system could be done based on the following stages as suggested by Sokoloff and Thorntons: (1) Teacher describes and executes the experiment (input: beam length, cross-section, material, load, support). The program will show the visual implication (deformation), but no other results. (2) Students make anonymous individual predictions about the results in a questionnaire. (Various interactive learning tools such as Kahoot or Socrative, with students answering using smartphones or laptops, could help this step run smoother). (3) The results of the student predictions are shown on the screen. (4) Students discuss in smaller groups or just with their neighbor. (4) The experiment is completed; all results are shown on the screen. (5) Open discussion about the results. The software would have to be adjusted in order to fit the above procedure. The results (except deformation) should be hidden, either on a separate page or activated by command. Finally the software should be tested and evaluated in one or more sessions.

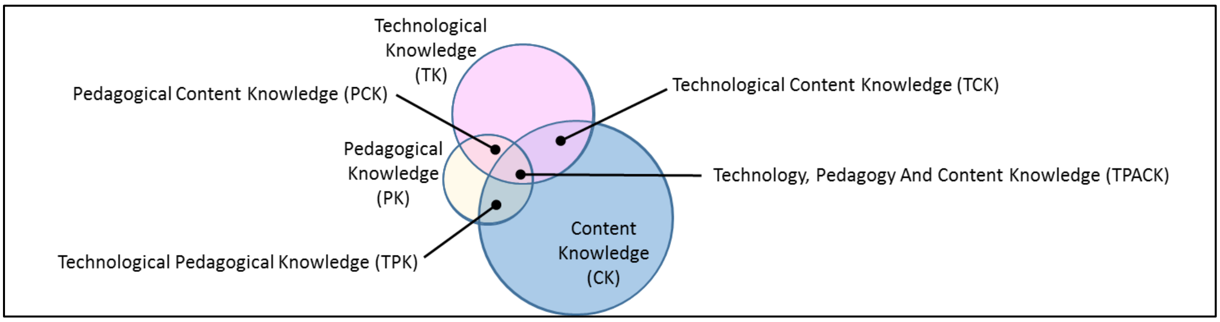

Figure 4. Dimensions of TPACK as experienced in the classroom

6. Conclusion

This article presents a reflection on using a self-made visualization program for teaching beam theory in a classroom setting. While we argue that the software was ripe for classroom implementation and for providing sufficient content knowledge for our students, our pedagogical approach was not. Our findings suggest that simply replicating a traditional lecture and replacing chalk drawings for digital models will fail. Thus, we would need to develop a proper pedagogical concept in addition to our program for making it a success. We will continue developing both the software and a related teaching approach to provide an overall successful learning system which then in turns may be applied by lecturers elsewhere.

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Investigation of Construction Stakeholders' Perception on the Effects & Cost of Construction Disputes in Swaziland

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Abstract:

Construction Projects are often delivered under a complex and uncertain environment, with claims and conflict being an inevitable part. It is vital to manage claims and conflict as soon as possible before they turn into disputes. The intent of this paper is to investigate the effects and cost of construction dispute in construction projects in Swaziland. The data used in this study were derived from both primary and secondary sources. The secondary data for the study was derived from the review of literature. The primary data was obtained through the use of a questionnaire which was distributed to client (government), contractors and consultant representatives (quantity surveyor, civil engineer, architects, project managers and mechanical and electrical engineers), only organizations registered with the ministry of public work and transport in Swaziland and other professional bodies were surveyed. Findings enacting from the survey revealed that the major effects of construction disputes in Swaziland construction projects were loss of productivity, loss of company reputation, loss of business viability, loss of profitability. With respect to cost of disputes, the findings revealed that hidden cost; indirect cost; direct cost, were major factor for cost of disputes. The results of this study contribute to the body of knowledge and provide valuable insight to actual effects and cost of disputes in Swaziland construction projects, hence the effects are ugly. The study recommends that every stakeholder in the Swaziland construction industry familiarise themselves with the strategies of avoiding construction dispute to avoid the occurrence. Also the government must take up an initiative of educating all stakeholders about dispute avoidance, it would save the project and company fortunes.

Keywords: Cost of dispute, Effects of dispute, Swaziland

1. Introduction

The construction industry has become very complex, high risk and competitive environment in which participants with different views talents and level of knowlegde of construction process work together, hence, there is a great deal of dispute exist within the construction industry. (Sinha &Wayal, 2008; Cakmak & Cakmak, 2013 Kumaraswamy & Yogeswaran, 1998 and Semple et al., 1994). Therefore, the diference in perception among this various stakeholders is very high, hence disagreement about something is inevitable. Disputes are the main factors that contribute to delays, disruption of construction schedule, increased projects cost and badly influence relationships between projects participants. Moreover, disputes are the main factors which prevent the successfully completion of the construction project (Cakmak & Cakmak, 2013).

Construction dispute materialise if costruction claims are not settled in an effective, economical and timely maner. Hence dispute does not exist until a claim has been submitted and rejected (Sinha & Wyal, 2008; Semple et al., 1994). For example, when one party feels that they deserve monetary or extension of time or compensation, they then submit a claim. Therefore, a claim is the assentation of a right to money, property or remedy (Sinha & Wyal, 2008).

There are very few projects that do not give rise to some form of dispute during the construction stage. Dispute can be very disruptive and expensive, particulary if allowed to escalate and proceed to formal detemination by court of law (Chapman, 2006). Hence resolving disputes can be expensive and time consuming, it is therefore, crucial to manage disputes proactively to ensure that early settlement is achieved. Any stakeholders in the

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construction projects can generate dispute and the effects are ugly (Jahren, et al., 1990). Effects of dispute could cripple a company badly and some of them are loss of productivity, cost overrun, loss of profitability, time delays, breakdown in co-operation between parties(Sinha & Wayal, 2008; Jahren et al., 1990). Therefore, since some disputes are not avoidable, proper management of conflict will ease the effect it has on the construction process, however resolution should follow quickly.

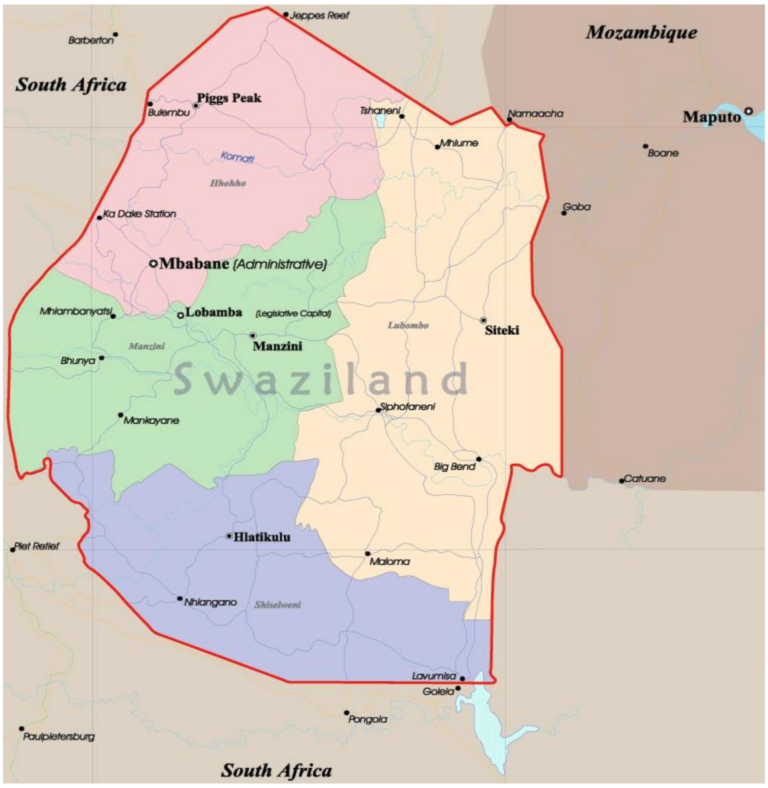
There are very reliable few studies on cost of disputes and thus very little justification for implementation of these approaches in terms of quantification of costs and measured savings to be achieved. Diekmann and Nelson (1985), state that construction industry frequently fails to analyse the actual cost associated with dispute occurrences. The types of cost that are experienced due to dispute causation are transactional cost, direct cost, indirect cost and hidden cost (Gebken et al., 2006).

There has been a considerable research done to determine the effects of dispute in construction industry and consistently the same variables are identified and continue to manifest in projects. However, there has been a gap in investigation of professional opinion within the construction industry of the effects and cost of construction dispute. Disputes have become an endemic feature of the Swaziland construction industry. Hence, this paper aims to investigate the effects and cost of construction disputes in construction projects in Swaziland.

2. Swaziland

Swaziland is Southern African country and shares its boards with South Africa on three sides and Mozambique on one side. Swaziland is very small country and because of its location, it is heavily dependent on its neighbours for access to the sea, to the markets and to outside suppliers (SACU- Kingdom of Swaziland, 2009). Swaziland's population is estimated at around 1.4 million. Swaziland is Africa's last monarchy, ruled by King Mswati III, subject to constitution of 2005. The constitution involves some democratic element and protection of human right (Miller, Holmes & Feulner, 2013: 413).

However political parties remain banned (Coppock, Forte, Ncube, Ooka, Richards & Vyas, 2008:2). The country is partial reliant on some natural resources found such as coal, clay, gold, diamond deposits, quarry stone, hydropower, timber and talc.(Miller et al., 2013:413).The Kingdom is divided into four districts namely Hhohho, Manzini, Lubombo and Shiselweni District. The capital city is Mbabane in the Hhohho District with a population of around 100,000. An authoritarian environment obtains in Swaziland and this makes the governance system to be weak and vulnerable to corruption. The courts are inefficient and organisations often pursue out of court settlement (Miller et al., 2013:414).



3. Swaziland construction industry

The construction industry (CI) in many countries is a key component of economic growth. For the developing countries the construction industry plays even a greater role in development and poverty alleviation by providing access to basic services and transport facilities (Odediran et al., 2012). The construction companies operating in Swaziland range from small local contractors to major companies with the capability to carry out highly specialised projects. The large contractors employ about 20,000 people. The range of work undertaken in the construction industry covers small buildings, multi-level projects, roads, dams and infrastructure. Therefore, the CI is a key source of work and income in the Kingdom. The overall contribution to the Gross Domestic Product (GDP) by the construction industry was 5.8% in 2002, but it has dropped down to 2.8% in 2013 (Swaziland Business year book 2002, Central bank of Swaziland).

Government is the major client in the construction industry of Swaziland. The ministry of Public Works and Transport is the Government's implementing agency on behalf of all ministries with regard to all construction capital projects (Mvubu &Thwala, 2009). The Swaziland Government through the ministry of Public Works and Transport also has a responsibility to educate contractors and subcontractors about government's expectations of the quality of work; the process of tendering and the information required (Mvubu &Thwala, 2009). The Government of the kingdom of Swaziland, through its 25- year National Development Strategy has identified the construction sector as a priority area to provide the impetus on improve the social and economic development of the country. However, the Agriculture industry is the one that leads by contributing more to the economy of the country.

4. Literature review

4.1. *Dispute*

Dispute is defined as an assertion of opposing views or claims or disagreement as to rights (Merriam- Webster's Dictionary of law, 1996). Dispute can be caused by negligence in understanding the terms in the contract, for example disputes on misunderstanding and also payment (Thomas, 1992 &1994). Reid and Ellis (2007), in a paper titled 'Common sense applied to the definition of a dispute' make the argument that there is no definitive meaning of dispute and a dispute according to Reid and Ellis doesn't not exist until a claim has been submitted and rejected, a claim being a request for compensation for damages incurred by any party to the contract. The definition of Dispute is a problem or disagreement between the parties that cannot be resolved by on jobsite or on-site project managers. Moreover, the definition carries the emphasis on jobsite or on-site disputes are firstly seen as occurring on site then escalating upwards through the organisational hierarchy (Love, et al .,2007).

4.2. *Causes of construction dispute*

In the construction practice, there are numerous of construction disputes that occur largely through many reasons between the various parties in a design/ construction effort. The construction disputes may occur from the initial stage until the closeout stage of the project. The occurrence of construction disputes can lead to negative impact towards client organisation. The construction work progress will be slow due to disputes between the contractor and client, subsequently; the cash flow also suffers terrible (Love et al, 2007).

Construction disputes are generally contract related so construction lawsuits fall in the filling category of civil suites (Tucker, 2005:27). On the contrary, construction disputes pose a significant problem for the construction industry. Roffman, (2003), surveyed 350 senior executives in the real estate and the construction industry and almost 50% reported an increase in construction related disputes over the last few years.

One may ask what is different about construction which makes it so confrontational and have a high potential for disputes? The answer is construction is procured and completed in a manner which lends its self to numerous potential disputes. The process includes an owner's version, selection and completion of a formal design, selection of a construction team which usually includes many specialist subcontractors, actual construction, and ultimately building commissioning and turnover (Roffman, 2003).

4.3. *Effects of disputes in construction companies*

Problems of construction disputes has an effect on all stakeholders which may lead to an inequitable mode of project delivery such as reduced margins, increased costs and even reduced the quality and levels of service (Al Momani, 2000). Most disputes are of minor nature and are settled quickly, fairly and amicably by the building team (Tucker, 2009). However, from time to time, more serious issues come into disputes and when this happens the building team should make mean to reach a fair settlement by negotiation or other means of dispute resolution mechanisms available which are mediation, arbitration, amongst others. The consequences of construction disputes will not benefit the stakeholders in the construction project (Love et al, 2007). Moreover, disputes may affect cash flows (disputes, affect insurance coverage (liability risk exposure), insurance rates (indemnity payment and cost of settling claims), overheads (personal time to defend and settle, plus attorney's fees) and reputation (publicity from large suits) (Rubino, 1981:13).

Therefore, the effects of construction disputes in an organisation can be summarised as follows:

I. Additional expense in managerial and administration
II. Possibility of litigation cases
III. Loss of company reputation
IV. Loss of profitability and perhaps business viability
V. Loss of productivity
VI. Time delays and cost overruns
VII. Extended and/ or More complex award process
VIII. Loss of professional reputation
IX. Break down in cooperation between parties
X. Diminution of respect between parties and deterioration of relationship and break down in cooperation
XI. Additional expense in administration
XII. High tender prices
XIII. Rework and relocation cost for men, equipment and materials
XIV. Cash flow (Dispute affect insurance coverage and liability risk exposure).

4.4. *Cost of Dispute*

There are very reliable few studies on cost of disputes and thus very little justification for implementation of these approaches in terms of quantification of costs and measured savings to be achieved. Diekmann and Nelson (1985), state that construction industry frequently fails to analyse the actual cost associated with dispute occurrences. Gebken et al (2006), attempted to quantify the cost arising from dispute resolution by unravelling the complexity of the cost of disputes and develop useful information to make worthwhile comparisons between different ways that disputes are currently managed by the industry.

Also there are transactional cost which are defined as the cost that are incurred because of the presence of a dispute including direct cost such as expenses paid to lawyers, accountants, claim consultant and other expenses. Indirect cost: are salaries and associated overheads cost, company managers, and other employees who have to assemble the facts, serve as witness and otherwise process the disputes. Hidden costs: are the inefficiencies, delays, loss of quality that disputes cause to the construction process itself, and the coast of strained business relations between the contracting parties (Love, et al, 2009:11). According to Gutierrez, Panuwatwanich & Walker (ND), Hidden cost also include time –value of money damage of reputation and long term business relationship, and opportunity costs, among others. Therefore, because of the high cost of dispute identified above, it is important to understand the critical factors that lead to disputes so they can potentially be minimized, or avoided altogether.

5. Research Methodology

The data used in this paper were derived from both primary and secondary sources. The primary data was obtained through the survey method, while the secondary data was derived from the review of literature and archival records. The primary data was obtained through the use of a structured questionnaire survey. This was distributed to a total of 90 construction professionals that included; client (government), contractors, consultants' representative's quantity surveyors, civil engineers, architect,etc who are currently involved in construction of public projects in Swaziland. Out of the 90 questionnaires sent out, 63 were received back representing 70% response rate. This was considered adequate for the analysis based on the affirmation of Mcneill & Chapman, (2005) since the result of a survey could be considered as biased and of little value if the return rate was lower than 30 to 40%. The data presentation and analysis made use of frequency distributions and percentages of all the respondents. The research was conducted between the months of June to August, 2014.

5.1. *Analysis*

In this study, the analysis employed a simple statistical methodology, which is descriptive statistics (mean, mode, median, number, percentage, range, standard deviations). The data was precoded by listing different numerical codes against different responses, transforming the data format from textual to numerical was done by coding and inputing data on SPSS so as to enable anlysis using the relevent statistical techniques (Henn, Weinstein & Foard,2006).

A five point Likert scale was used because it allows a range of responses to be generated including neutral answers and does not force a decision as in the case of "yes" or "no" type of questions. The question sought to establish the critical success factors that contribute to cost of poor quality work, with regard to the identified problems and factors from the reviewed literature. The adopted scale allowed individuals to express their opinion on how much they strongly agreed or strongly disagreed with a particular statement.

1 = Strongly disagree
2 = Disagree
3 = Neutral
4 = Agree
5 = Strongly agree

The calculation of scores was also done to establish the level of significance of factors to the level of quality in the construction industry in Swaziland. A score was given to each factor as assessed by the respondents. The score made it possible to compare how much the respondent agree with the factors or statement. The five-point scale was transformed to a Mean Item Score (MIS) for each of statements. A weight was assigned to each response. The indices were then used to determine the rank of each item. These rankings made it possible to cross compare the relative importance of the statements as perceived by the respondents. The Mean Item Score (MIS) is ranked in descending order (from the highest to the lowest). The Mean Item Score (MIS) was derived from the following formula (Lim and Alum, 1995).

$$MIS = \frac{1n1 + 2n2 + 3n3 + 4n4 + 5n5}{\sum N}$$

Where;

n_1 = number of respondents for strongly disagree

n_2 = number of respondents for disagree

n_3 = number of respondents for neutral

n_4 = number of respondents for agree

n_5 = number of respondents for strongly agree

N = Total number of respondents

6. Findings and Discussion

Findings from the 63 respondent revealed that 63% were males and 37% were female. Further findings revealed that 19% of the respondents were civil engineers, 18% of the responded were quantity surveyors, 11% were construction managers, 10% were project manager and construction project manager, 7% were electrical engineers, site managers and health and safety. Most of the respondent had a working experience of more than 5 years, 60% of the respondent had 5 or more years, 32% had 4years experience, 13% had 3 years' experience, 3% had 2 years and lastly 2% had 1-year experience. Respondent who were involved in civil and building projects were 44.6%, 27.7% of the respondent were involved in buildings, 10.8% were involved in civil work only, 9.2% were involved in electrical work, 6.2% were in Mechanical work and lastly 1.5% were involved in other projects. Respondent on the value of work executed were 37% who had executed 100-200million, 200 million were 24%, 21% had executed 10-20million,18% of the respondent had executed20-100 million and 2% had executed 2-5million. 59% Respondent had 5 or more construction dispute, 19% had encounter 3 dispute, 10% had encountered 2 & 4 dispute, and 3% had encounter one dispute

6.1. *Effects of Disputes in Construction Projects*

The respondents were asked to indicate the extent of possible outcomes / effect of a construction dispute in construction projects. Most of the respondents reveals that loss of productivity had a major effect on construction projects and it was ranked first with a mean score of 4.8 and SD= 1.025; loss of business viability was ranked second with a mean score of 4.29 and SD= 0.982; Loss of profitability was ranked third with mean score of 4.23 and SD= 1.015; Time delay was ranked fourth with a mean score of 4.19 and SD= 0.938; Loss of professional reputation was ranked fifth with a mean score of 4.18 and SD= 1.064; break down in cooperation between parties was ranked sixth with a mean score of 4.11 and SD= 1.088; Cost overruns was ranked Seventh with a mean score of 4.10 and SD=0.918 and loss of company reputation was ranked eighth with a mean score of 4 and SD= 1.040. Furthermore, additional expense in administration was ranked third last (13) with a mean score of 3.55 and SD= 1.035; relocation cost of workers was ranked second last (14) with a mean score of 3.54 and SD=1.134 and lastly additional managers cost was ranked last fifteen with a mean score of 3.47 and SD= 0.987 (Table 6.1).

Table 6.1 Effects of construction disputes

Factors	$\bar{x}$	σX	R
Loss of productivity	4.8	1.025	1
Loss of business viability	4.29	0.982	2
Loss of profitability	4.23	1.015	3
Time delays	4.19	0.938	4
Loss of professional reputation	4.18	1.064	5
Break down in cooperation between parties	4.11	1.088	6
Cost overruns	4.10	0.918	7
Loss of company reputation	4.00	1.040	8
Diminution of respect between parties	3.97	1.119	9
Relocation of Equipment	3.56	1.125	10
Rework/ repetition of work	3.73	1.119	11
Relocation of Material	3.58	1.124	12
Additional Expense in administration	3.55	1.035	13
Relocation cost of workers/ labors	3.54	1.134	14
Additional Managers cost	3.47	0.987	15

σX = Standard deviation; $\bar{x}$ = Mean item score; R = Rank

6.2. *Cost of Construction Dispute*

Respondent were asked to indicate the extent of costs incurred during or after dispute resolution. The type of cost incurred were grouped into three categories, therefore, Table 5.2 represent direct cost category. Respondent ranked fees and expenses paid to lawyers first with a mean score of 3.56 and standard deviation (SD) = 1.161; fees and expenses paid to claim consultant was ranked second with a mean score of 3.25 and SD= 1.121 and lastly fee & expenses paid to accountant was ranked third with mean score of 3.22 and SD= 1.099.

Table 6.2: Type of costs- Direct cost

Type of cost		$\bar{x}$	**σX**	**R**
Direct cost	Fees & expenses paid to lawyers	3.56	1.161	1
	Fees & expenses paid to claim consultant	3.25	1.121	2
	Fees & expenses paid to accountant	3.22	1.099	3

σX = Standard deviation; $\bar{x}$ = Mean item score; R = Rank

Under the category of indirect cost is presented in the following Table 5.3, respondent ranked salaries first with a mean score of 3.65 and SD=0.925; cost arising from reduced onsite productivity was ranked second with a mean score of 3.59 and SD= 0.981and company managers were ranked third with a mean score of 3.56 and SD= 1.133. However, overheads to lawyers and employees assemble the fact, served as witness were ranked the least with a mean score of 3.33 & 3.13 and the SD= 1.016 &1.218 respectively (Table, 6.3).

Table 6.3 Types of costs- Indirect cost

Type of cost		$\bar{x}$	**σX**	**R**
Indirect cost	Salaries	3.65	0.925	1
	Cost arising from reduced onsite productivity	3.59	0.981	2
	Company managers	3.56	1.133	3
	overheads of lawyers	3.33	1.016	4
	Employees assemble the facts, served as witness	3.13	1.218	5

σX = Standard deviation; $\bar{x}$ = Mean item score; R = Rank

The Table 5.4 below presents the respondent findings under the hidden cost category: cost of strained business relation between the contracting parties was ranked first with a mean score of 3.7 and SD= 1.077 and lastly loss of quality that dispute cause to the construction process itself was ranked second with a mean score of 3.62 with SD= 1.069 respectively

Table 6.4: Type of costs- Hidden cost

Type of cost		$\bar{x}$	**σX**	**R**
Hidden cost	Cost of strained business relation between the contracting parties	3.70	1.072	1
	Loss of quality that dispute cause to the construction process itself	3.62	1.069	2

σX = Standard deviation; $\bar{x}$ = Mean item score; R = Rank

7. Conclusion and Recommendation

7.1. *Conclusion*

Literature revealed that the effects of disputes in construction projects were additional managers cost, Additional Expense in administration, relocation of material, relocation of equipment, time delays, breakdown in cooperation between parties, loss of professional reputation, loss of profitability, loss of business viability. However, from the survey findings obtained from the respondents it revealed that loss of business viability; profitability; loss of professional reputation; break down in cooperation between parties and time delays were the major effects or had major impact on construction projects. However, it is interesting to note that some of the effects pointed out by Tucker 2005 in his thesis that have high impact on construction projects, in Swaziland the responded felt that they don't have any effect in construction projects such as relocation of equipment; relocation of material; additional expense in administration; and additional cost to managers.

Literature again revealed that the cost incurred during or after a construction disputes, were hidden cost such as cost of strained business relation between the contracting parties and Loss of quality that dispute cause to the construction process itself. Indirect cost such as salaries, cost arising from reduced onsite productivity and company managers. Direct cost such as fees and expenses paid to lawyers and claim consultant. Moreover, from the survey findings obtained from the respondents, hidden cost such as cost of strained business relation between the contracting parties and Loss of quality that dispute cause to the construction process itself were ranked the highest. Followed by indirect cost such as salaries, cost arising from reduced onsite productivity and company managers were ranked the second highest. Lastly, direct cost such as fees and expenses paid to lawyers and claim consultant, were ranked the least as the cost that are incurred during or after a construction dispute is resolved.

7.2. *Recommendation*

The study has revealed research gap which might be fruitfully pursued, such as the as the actual cost of construction dispute, if one can be allowed to access the court case so we can be able to quantify the exact cost used in resolving a construction dispute.

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Creative Construction Conference 2016

A Thematic Review of Main Researches on Construction Equipment over the Recent Years

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Abstract

A considerable body of literature has been dedicated to research studies on construction equipment. Many topics have been discussed and analyzed with various conclusions being reported. However, research papers published in relation to construction equipment, are highly diversified and there is a lack of systematic analysis and classification. Hence, a complete understanding of the topic is not possible, nor is the assessment of any future research direction. A meta-analysis of the latest journal papers dedicated to construction machinery would not only delineate the different fields the academic research has been concentrated on, but it would additionally reveal potential gaps for future research.
In the current study, through a systematic review of the academic literature that has been published over the last decade primarily identified via online databases, main research themes such as optimization, maintenance/downtime, productivity, robotics and automation, operator's competence, innovation and environment are defined and discussed and future research directions are proffered. The outcome of this paper will facilitate future researchers to develop an appreciation of the progress on construction equipment and its potential functions and provide future research directions on this field.

Keywords: construction equipment; optimization; productivity; maintenance; research

1. Introduction

"Construction equipment" (CE) or "Heavy equipment" refers to heavy-duty self-propelled vehicles, specially designed for executing construction tasks. Its use has a significant importance in the successful realization of civil projects; it therefore represents a major capital investment for the construction industry. In this research, the term CE refers to the machinery that is used especially for earth-moving operations. Those earthworks mainly consist of four basic processes: excavating, hauling, spreading, and compacting [1]. Typical earthworks are building foundation work, road construction, dam construction, airport construction and strip-mining. Depending on their kind and size the earth-moving operations are carried out by single machines working independently or by sets of machines working together and consist of excavators, dump trucks, loaders, compaction rollers, graders, scrapers, etc.

There is a lot of research work on CE. However, research papers published in relation to CE, are highly diversified and there is a lack of systematic analysis and classification. Hence, a complete understanding of the topic is not possible, nor is the assessment of any future research direction. This mate-analysis of the latest journal papers dedicated to CE would not only delineate the different fields the academic research has been concentrated on, but would reveal also the potential gaps for future research. A previous holistic research on this subject can only be traced in the review conducted by Edwards and Holt [2]. In their work, the authors highlighted the following points as research directions for the future:

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- Machine maintenance might develop with more sophisticated predictive models that enable "just-in-time" component replacement,
- Concerning the application of the global system for mobile communications facilities, it emerged that there is scope for future research, since plant location and spatial data might be expanded to embrace large fleet management,
- The concepts of autonomous machine control, automated systems and robotics might all be more attractive to researchers in the future given the advantages of "unmanned" machines, a matter which is also related to aspects of safer working conditions.
- The adoption of nanotechnology and the production of hybrids are potential routes of development,
- There is a need to enhance research sharing between the industry and the academic community.

Given the above, an updated review on the latest published academic papers dedicated to construction machinery would not only indicate the fields the research was eventually directed to, but it would additionally reveal any potential gaps for future research. The paper begins by presenting the method employed to determine the major research outcomes, followed by a review of the academic papers. Principal research themes are identified; practices and possible gaps in research are discussed and future research directions are proffered. Finally, conclusions are drawn.

2. Methodology

A search (2016) via online databases such as SCOPUS, ASCE, ELSEVIER and EMERALD was carried out to determine the major research themes related to the field that have been published over the last decade. Search keywords like construction equipment, productivity, optimization, research, earthmoving operations, were involved in the title, abstract or keywords of the articles searched.

Editorials, book reviews, articles in press, conference/seminar reports, discussions and articles published more than a decade ago were excluded from this research. Nevertheless, where it was considered necessary for reasons of documentation, some extra papers were added. After collecting the published work, an analysis was performed in order to classify the main areas of interest. It must be clarified that the sample was indexed in a subjective manner and that some themes might present a lot of commonalities due to the complex interrelationships between them. For example, *"Optimization"* and *"Productivity"* present commonalities as the best fleet selection is determined by productivity constraints of each CE. Moreover, it is acknowledged that the review is in no case exhaustive. The themes and number of papers falling therein are shown in Table 1:

Table 1: Number of papers falling within the seven Themes identified

Themes identified	Number of papers detected
Optimization	12
Maintenance/ Downtime	11
Productivity	12
Operator's competence / Health & Safety	11
Robotics/ Automation	9
Innovation	10
Environment	8
Sum	73

3. Literature review

3.1. Optimization

Optimization deals with finding optimal decisions under the given constraints considering the number of possible alternatives. This theme covers a variety of subjects that involve decision-making to increase resource efficiency of use, minimize construction cost, reduce construction time and improve quality. Construction project scheduling has received a considerable amount of attention over the last years. Many models were developed to assist contractors in optimizing planning of earthmoving operations. For example Moselhi and Alshibani [3], developed a model that utilizes genetic algorithm, linear programming, and geographic information systems (GIS) to support management functions. As such, Zhou et al. [4] presented a review of the methods and algorithms that have been developed to examine the area of construction schedule optimization. The developed algorithms for solving this problem were classified into three methods: mathematical, heuristic and metaheuristic. Appropriate fleet selection is a prominent issue, attracting strong research interest. Zhang [5] proposed an integrated framework for multi-objective simulation–optimization determining optimal equipment configurations of earthmoving operations; Hola and Schabowicz [6] presented a methodology for selecting an optimum set of collaborating earthmoving machines with the criterion of the minimum time needed or the minimum cost of carrying out the earthworks. Jrade et al. [7] introduced a model with the aim to enable the selection of the optimum equipment fleet based on simple economical operation analysis. Contractors have also started to acknowledge and use the telematics technology as a reliable solution for timely collection of their equipment fleet data. This sub-theme has attracted a particular interest amongst researchers. For instance: Said et al.[8] presented novel methodologies to support heavy equipment fleet managers in using telematics data into two major tasks: fleet use assessment and equipment health monitoring; Alshibani and Moselhi [9] developed an optimization simulation model that uses Global Positioning System (GPS) for fleet selection for earthmoving operations; Akhavian and Behzadan [10] presented a remote tracking technique developed to capture real-time field data from construction equipment to predict the future performance of a construction system in addition to monitoring if all pieces of equipment are operating according to the plan; Pradhananga and Teizer [11] presented the use of low-cost easy-to-install GPS data logging technology for tracking and analyzing construction equipment operation. Overall, construction equipment management can improve construction project performance and contractor corporate performance. Samee and Pongpeng [12] not only studied these relationships by collecting contractors' opinions, but also examined the causal relationships between the construction equipment selection factors and the competitive advantage of contractors [13]. Moreover, Aziz et al. [14] presented a smart optimization model, which incorporates the basic concepts of Critical Path Method with a multi-objective Genetic Algorithm in order to support the balance between time, cost and quality simultaneously for mega construction projects. Finally, Shawki et al. [15] displayed a tool for simulating earthwork operations in most applications of construction.

3.2. Maintenance/Downtime

Maintenance plays a key role in reducing cost, minimizing equipment downtime, improving quality, increasing productivity and providing reliable equipment and as a result achieving organizational goals and objectives [16]. Construction equipment performs to its optimum level if it is maintained properly. Downtime resulting from machine breakdown during operations is one of the most unanticipated factors that have a substantial impact on equipment productivity and organizational performance as a whole [17]. To overcome downtime problems, contractors need to understand the dynamics of downtime as well as its influential factors, and thus manage their equipment as a dynamic process rather than one that is static [18]. In order to be effective, predictive maintenance strategy integrates machine data, prognostics, and remote diagnostic tools, which are critical to increasing machinery uptime. Approaches such as condition-based maintenance are being implemented to deal with the situation. Sensors are applied to detect changes in equipment components. With these solutions, contactors gain insight into operations to understand machinery's health and avoid downtime and excessive maintenance costs. Chen et al. [19] developed a distributed condition monitoring and fault diagnosis system for the hydraulic system of large complex construction machinery, taking into account that more than 50% of the faults of construction machinery is related to its hydraulic system. Equipment health-monitoring is a proactive maintenance tool to estimate the equipment's failure probability, and hence, Said et al. [8] developed a telematics-based equipment health-monitoring framework for collecting vital equipment performance parameters to continuously assess the condition of the equipment and detect signs of possible failure. Some researchers touched upon the factors and parameters that influence the deterioration process and the forthcoming downtime. For instance, Prasertrungruang and Hadikusumo [20] proposed a model that intends to facilitate a better understanding of the relationships among acquisition condition, operational practice, maintenance quality, disposal practice, and downtime consequences of heavy equipment; and Marinelli et al. [21] investigated the impact of various parameters (capacity, age, kilometers, maintenance) on the deterioration process of earthmoving wheel trucks using the statistical method of discriminant analysis. According to this method, any truck can be assigned to a specific condition level, depending on its parameters' values. This allows the effective planning of maintenance activities and the prediction of the consequences that are expected to occur due to the equipment's deterioration including downtime. Similarly, Marinelli et al. [22] presented an Artificial Neural Network (ANN)-based model for the prediction of earthmoving trucks' condition level using the aforementioned parameters as predictors. The model identified an exclusive connection of the condition level with the kilometers travelled and the maintenance level as the impact of the age and capacity was found to be negligible. Mohideen et al. [23] introduced a model that tackles unpredictable breakdowns in the construction plant and thus minimizes the breakdown time. The proposed model enables a quick recovery of the construction plant, according to the breakdown parameters derived from the previous history of the work records/environment. Mohideen and Ramachandran [24] proposed a breakdown code management to provide a focused and unambiguous approach to the maintenance crew to handle any kind of breakdowns in construction equipment. Additionally, Yip et al. [25] presented a comparative study on the applications of general regression neural network (GRNN) models and conventional Box–Jenkins time series models to predict the maintenance cost of construction equipment; and Curcuru et al. [26] proposed a methodology that minimizes the maintenance cost by determining the time at which the decision must be taken and the starting date of the maintenance process.

3.3. Productivity

The expected work output per time unit (hour or day), usually termed productivity, determines the cost and the duration of construction activities [27] and has consequently achieved much attention in literature. Panas and Pantouvakis [28] in their review research regarding construction productivity explored the different perspectives for measuring or estimating it; while Yi and Chan [29] conducted a systematic review of labor productivity in the construction industry to investigate the state of the art and trends in construction labor productivity. Concerning construction equipment, productivity estimation is heavily affected by the type of operational coefficients and the estimation methodologies taken into account. Based on this, Panas and Pantouvakis [30] proposed a structured framework for comparing different productivity estimation methodologies and evaluating their sensitivity with operational coefficients variation for excavation operations. Rashidi et al. [31] proposed a generalized linear mixed model to estimate the productivity of a common type of bulldozers and compared the outputs with the results obtained by using a standard linear regression model. It was proven that a significant increase in the accuracy and a remarkable reduction in the data variance can be achieved by using the proposed model. Telematics were also used for estimating productivity in near real time. For example, Montaser et al. [32] presented an automated method that utilizes GPS and Google Earth to extract the data needed to perform the estimation process; Montaser and Moselhi [33] demonstrated an automated system that integrates GPS and GIS in a web-based platform used for estimating, monitoring and forecasting productivity of hauling trucks in earthmoving works. Other researches in the field include those by Schabowicz and Hoła [34,35] who applied ANNs not only to predict productivity, but also to predict earthmoving machinery effectiveness ratios; by Marinelli and Lambropoulos [36] who proposed a new algorithmic method for scraper load-time optimization that achieves an improved modeling of scraper earthmoving operations and contributes toward a more efficient cost management and by Oh et al. [37] who developed a driver model for the wheel loader V-cycle working pattern and a 3D dynamic simulation model to analyze working performance and energy flow in each component of the wheel loader. Finally, the work of Rustom and Yahia [38] employed the use of simulation as an effective planning technique for estimating production rates in construction projects.

3.4. Operator's competence / Health and Safety

Operator's competence is the operator's ability to effectively and efficiently apply the machine to the work task. Operator's competence embraces not only aspects of productivity, but also health and safety (H&S) aspects. Regarding productivity, it is acknowledged that operator competence and operator motivation are two entirely different concepts, since a very competent operator can also be demotivated or simply idle. Holt and Edwards [39] in their work identified the superlative role of operator competence in relation to other productivity variables and presented a conceptual approach to overcoming subjective factors when estimating productivity. Concerning H&S aspects, training is widely considered to be one of the best approaches to the accident prevention. Operator training simulators are a key component of such initiatives to serve the purpose of keeping plants operating safely, with optimal performance and reliability. Simulated environments provide safe, controllable conditions in which operators can practice necessary skills such as critical thinking and decision making. The benefits of simulation training have potentially much to offer to the construction training industry particularly in the education and development of entrant level plant operators [40]. Guo et al. [41] suggested the use of game technologies to improve the safety of construction plant works. The game technology-based safety training method provides trainees with an easily operated multi-user virtual environment that allows them to try and study different methods of operating the plant, while helping them identify potential safety problems.

The inevitable coexistence of machinery and ground floor workers results in many work accidents on sites. According to Mc Cann [42] backhoes and trucks were involved in half the deaths with rollovers being the main cause of death of heavy equipment operators. In an attempt to alleviate fatalities and injuries in construction industry many researchers have focused on H&S aspects. Hinze and Teizer [43] in their paper highlighted that blind spots; obstructions and lighting conditions were the most common factors contributing to vision related fatalities. Given the above, Teizer et al. [44] developed a novel blind spot measurement to help identify the blind spots of equipment, to quantify and protect the required safety zone(s); Moreover, Marks et al. [45] presented a technique based on laser scanning for measuring blind spots of four different skid steer loaders and suggested that similar measurement data for several pieces of equipment can be used to provide design suggestions in the future. Teizer et al. [46] also applied a real-time proactive Radio Frequency warning and alert technology to improve construction safety by warning or alerting workers-on-foot and operators in a proactive real-time mode once equipment gets too close in proximity to unknown or other equipment. Similarly, Marks and Teizer [47] presented a test method to evaluate the capability of proximity detection and alert systems to provide alerts when heavy construction equipment and workers are too close to each other. The use of 3D visualization not only assists equipment control, but also improves operation efficiency and safety, and therefore Gai et al. [48] introduced a real-time visualization method to simultaneously assist heavy equipment operators to perceive 3D working environments at dynamic construction sites. However, Su et al. [49] warned that additional spatial information to the operator may increase mental workload, introduce difficulties in processing the information and consequently may cause malfunction and accidents.

3.5. Robotics/Automation

The use of robotics and automation (R&A) technology becomes essential to construction project success and creates possibilities for the construction company to realize a competitive advantage [50, 51]. A popular subtheme here is “unmanned construction”, i.e., work performed by remotely operated construction machinery that corresponds to an operator controlled robot. In environments with great exposure in hard conditions, remote machine operation is the preferred and most efficient solution for the operation of construction machines. Sasaki and Kawashima [52] in their work developed a remote control system for a backhoe with a pneumatic robot system, while Kim et al. [53] developed an excavator teleoperation system with movements of a human arm.

Furthermore, towards facilitating the use of automated construction equipment, Seo et al. [54] presented an excavation task planner devised to incorporate the intelligence of a construction planner and a skillful operator into the robotic control mechanism of an automated excavation system; Son and Kim [55] developed a system with a realistic 3D workspace representation of terrain, which has the capacity to provide interactive visual feedback to the operator of remotely controlled construction machines in order to make human-machine interaction more efficient. Other studies have focused on real-time monitoring and detection of the construction equipment in earthwork operations which is beneficial in several ways, such as productivity measurement and automated performance assessment, accident warning and locating resources in the construction site. For example, Azar et al. [56] introduced a vision-based system that detects the machines involved in loading actions, tracks them, recognizes their interactions, and estimates the cycle times; Azar and McCabe [57] presented two promising approaches combining available image and video processing methods to locate and distinguish dump trucks from other earthmoving machines in noisy construction videos; Memarzadeh et al. [58] presented a computer-based vision algorithm for automated 2D detection of construction workers and equipment from site video streams; and Golparvar-Fard et al. [59] presented a computer based vision method for equipment action recognition. Concerning spatial accuracy, Vahdatikhaki et al. [60] presented a novel approach to improve the quality of data captured by less expensive real-time location systems so that the location of the equipment can be accurately estimated.

3.6. Innovation

Papers in this theme deal with construction equipment development and applications of hybrid systems in construction machinery. Concerning equipment development, new methods and designs are implemented to enhance reliability, machine control, comfort, safety and reduce costs derived from failures and breakdowns. For example, Chen et al. [61] presented a systemic analysis of the cushioning performance of the high-pressure cylinder of an excavator’s arm that could be instructive to construction machinery designers and researchers, especially the high-pressure cylinder designers and the hydraulic system designers; Sun and Zhang [62] explored the characteristics and advantages of the hydraulic mounts used for vibration isolation of an earthmoving machinery cab compared with the rubber mounts; they found out that the cab system with quadratic damping hydraulic mounts are remarkably effective in mitigating the vibrations and in enhancing the cab comfort; and Solazzi [63] studied the boom and the arm of an excavator with the aim to replace steel alloy by aluminum alloy and thus reduce the weight of the machine.

However, the application of hybrid systems in construction machinery is the most popular sub-theme. Since advanced hybrid propulsion technology is the key to achieve fuel economy, construction machinery makers have put much effort in the research on applying hybrid propulsion techniques to further reduce fuel consumption and pollutant emissions. Lin et al. [64] presented applications of hybrid systems in construction machinery and highlighted the challenges encountered by the researchers and the construction machinery manufacturers, such as the high cost that needs to come down to the level of the conventional construction machinery with no sacrifice in performance. In the direction of energy saving and environment protection, Inoue and Yoshida [65] developed a hybrid system for a hydraulic excavator and Wang et al. [66] pointed out the trend of hybrid power loaders. Lin et al. [67] dealt with the method of how to regenerate the potential energy for a hybrid hydraulic excavator; and Hui and Junqing [68] proposed an energy saving scheme with parallel hydraulic hybrid system for a loader to capture the braking energy normally lost to friction brakes. Also, Wang et al. [69] in their paper analyzed the performance of the power train hybridization of hydraulic excavator and compared the main performance among the parallel, the series and the conventional configurations and Xiao et al. [70] dealt with control strategies of power system in hybrid hydraulic excavator.

3.7. Environment

Construction equipment is a major source of greenhouse gases and other air pollutant emissions. The emerging concept of sustainable or green construction emphasizes the urgency of minimizing the harmful impacts on the environment [71]. Manufacturers of earthmoving machines must address sustainability requirements, as well as remain competitive. Considering environmental issues during the planning phase could increase project's value [72].

Lewis et al. [73] in their work introduced the challenges to quantification of emissions from non-road construction vehicles and described associated governmental regulations and incentives for reducing emissions. Zhang et al. [74] developed a simulation method to estimate the emissions and noise by reflecting the uncertainty, randomness and dynamics in construction. Heidari and Marr [75] employed a portable emission measurement system for real-time emission measurement of construction equipment under actual operating conditions on site, to find out that in some pieces of equipment there were large discrepancies between measured emissions and those predicted by widely used models. Hajji [76] proposed a methodology for estimating fuel use and CO_2 emissions for some common earthwork activities performed by bulldozer, excavator and dump truck to help the contractor estimate the total expected polluting emissions for the project, which would be valuable information for a preliminary project environmental assessment. Selecting the most appropriate equipment concerning its environmental impacts is highly challenging. For this, Waris et al. [77] focused on determining selection criteria based on the fundamental concept of sustainability. In other papers, Ahn et al. [78] used low-cost accelerometers to measure the operational efficiency of construction equipment and monitoring environmental performance and Ng et al. [79] presented an eco-approach to enable operators to achieve optimal productivity for fuel efficiency of a hydraulic excavator. The research revealed that the combinations of various engine speed settings and bucket cut depths can increase productivity and reduce greenhouse gas emissions.

4. Discussion

In our era where civil engineering projects are more demanding in terms of more cost-effective solutions and environmentally friendly use of resources (construction equipment, materials, labor), the advancements in the CE industry focuses mainly in the following areas [80, 81, 82, 83]:

- Higher production rates with shorter cycle times and better performance
- Usage of several software applications for better CE management: increased productivity, efficiency, safety and operational analysis
- Innovations in remote diagnostics tools for proactive maintenance
- Ergonomic design that focuses mainly on the human being by offering better cabin conditions
- Remote control of the CE through the use of neural networks applications; the autonomous machine control and use of robotics (“unmanned” equipment)
- Fewer gas emissions by using hybrid engines
- Usage of lightweight materials for construction and hence better performance with lower fuel consumption

All the previously mentioned issues are well established in the literature of the last decade. Research concerning optimization tends to focus on operational analysis regarding the use of the appropriate fleet selection for specific construction method, time and cost constraints. Collection of performance data, remote control of proactive maintenance, automation and “unmanned” machines also attend to the demands for lower construction costs. Regarding the maintenance/downtime theme, condition monitoring helps to accurately assess the performance and operating condition of critical equipment. Concerning the theme of productivity, research includes the integration of telematics for tracking machine location, fuel consumption, availability and idle time. Future research efforts are directed in utilizing state-of-the-art technology to provide real-time spatial and performance data for even more effective equipment management. Regarding the operator’s competence, emphasis is given on the use of simulators and game technologies to safely train them and consequently advance their skills and enhance their levels of proficiency in a cost-effective way. Through the use of applications simulating worksites, the machine operators gain familiarization and understanding of machine controls, learn proper operating procedures and discover ways to maximize productivity. Regarding the theme of innovation, the design of hybrid engines has attracted a considerable amount of attention amongst researchers. The machine’s ability to collect, store and release energy during operation, enables lower fuel consumption and the potential for increased productivity, while decreasing the amount of harmful emissions released into the air. Remotely controlled unmanned construction equipment is the new trend in R&A intending to automate the construction site, leaving humans to program and control the project’s progress. Where high reliability and resilience to harsh environmental conditions are required, unmanned construction equipment can play a valuable role. In this field, manufacturers going one step further, already investigate the co-existence of unmanned construction equipment and unmanned aircraft (drones that provide 3-D models of the terrain) for routine construction. Finally, regarding the protection of the environment, the holistic approach combines the efficient and effective operation and the application of the correct environmental policies. During the two last decades the European and American policies have determined the requirements for the limitation of air pollution. The use of new materials for energy consumption as the biodiesel, biogas and dimethyl ether constitute alternative, renewable energy sources. As construction industry faces increasingly restrictive environmental regulations, future research will strive to facilitate “cleaner” machines to meet regulatory requirements.

5. Conclusions

The main conclusions of this research can be summarized as follows:

1. The academic research work regarding CE over the last decade has focused on the following thematic areas:
   a. Optimization, b. Maintenance / Downtime, c. Productivity, d. Operator’s competence / Health and Safety,
   e. Robotics / Automation, f. Innovation, and g. Environment.
2. The themes cannot be considered as completely distinct due to the interrelationships between them.
3. The areas on which the construction equipment industry has currently focused are embraced by the academic research community and vice-versa.
4. The advancements in technology have led to the use of remote control and maintenance systems improving the organization and controlling the performance of a construction equipment fleet. Moreover, R&A are working on “unmanned” machines that will do the job according to the requirements of the humans programming and controlling the project’s progress.

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Investigating the Effectiveness of Beach Fill Projects in the Northeast Region of the United States

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Abstract

The Atlantic coastline is constantly evolving with the persistent pressure of hurricanes and other coastal storm surges. Hurricane Sandy was the most recent hurricane to make landfall in the Northeast and although the eye of the storm was through New Jersey, the entire Atlantic coast from Maine to Florida was impacted. Sandy was the second costliest storm in US history with some damage estimates totaling as high as 75 billion dollars [1]. The storm also resulted in 233 direct and indirect fatalities [2]. This research study examines past hurricane and storm events that have led to the construction of beach fill projects in the northeastern region of the United States. A beach fill project consists of mechanically placed sand to fill a specified area known as a beach template. These massive mounds of sand create a physical barrier between the vulnerable structures on the shoreline and the Atlantic Ocean. The beach fills are designed to absorb and disperse the ocean wave energy in order to protect property from destruction and reduce the erosion of shorelines. These projects are designed and implemented by the US Army Corps of Engineers. Objectives of this study were to investigate the factors influencing the construction of these projects, identify the unique and challenging quality assurance process and identify the benefits and risks of beach fills to towns and states. This research specifically focuses on the town of Long Beach Island and the State of New Jersey. Through literature reviews, interviews and surveys there is strong evidence that beach fill projects are favorable to invested parties, they are attributed to protecting our coastal structures and coastal economies and the benefits far outweigh the risk.

Keywords: beach fill; coastline; erosion; property; quality

1. Introduction

1.1. *Background*

The damage from super storms and hurricanes can be devastating. Naturally, the federal government does everything in its power to prepare for such disasters. One attempt to mitigate the risk is through the use of coastal storm damage reduction projects. The first line of defense for heavily trafficked beach areas in the Northeast Region of the United States are construction projects known as beach fills. A beach fill project consists of mechanically placed sand to fill a specified area known as a beach template. These massive mounds of sand create a physical barrier between the vulnerable structures on the shoreline and the Atlantic Ocean. The beach fills are designed to absorb and disperse the ocean wave energy in order to protect these adjacent structures from destruction. These projects are designed and implemented by the US Army Corps of Engineers.

Hurricane Sandy was the most recent hurricane to make landfall in the Northeast and although the eye of the storm was through New Jersey, the entire Atlantic coast from Maine to Florida was impacted. Sandy was the second costliest storm in U.S. history with some damage estimates totaling as high as 75billion dollars [1]. The storm also resulted in 233 direct and indirect fatalities [3].

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It is estimated that for every dollar the federal government spends on flood mitigation, it saves and average of $4 in disaster relief after the next devastating storm [6]. The Sandy Recovery Program consisted of 5.1 billion dollars. Storms similar in size and magnitude to that of Hurricane Sandy are capable of eroding large portions of beaches all the way back to the edge of homeowner properties. These storms have also been known to completely remove the dunes of sand that are much higher than the elevation of the normal ocean levels (Figure 1). Along with absorbing wave energy, the beach fills serve to reduce flood risk by preventing water from overtopping dunes and flooding communities situated behind the beach. Beach fills are designed to be sacrificial in nature, meaning that the oceans wave energy will eventually wash the sand into the ocean and there will be a need to mechanically place more sand. Currently, the budget allows for a fifty year replenishment cycle for beach fill construction projects. The replenishment of sand is dependent upon the severity of the storm. However, USACE typically replenishes the sand every two to five years per project.

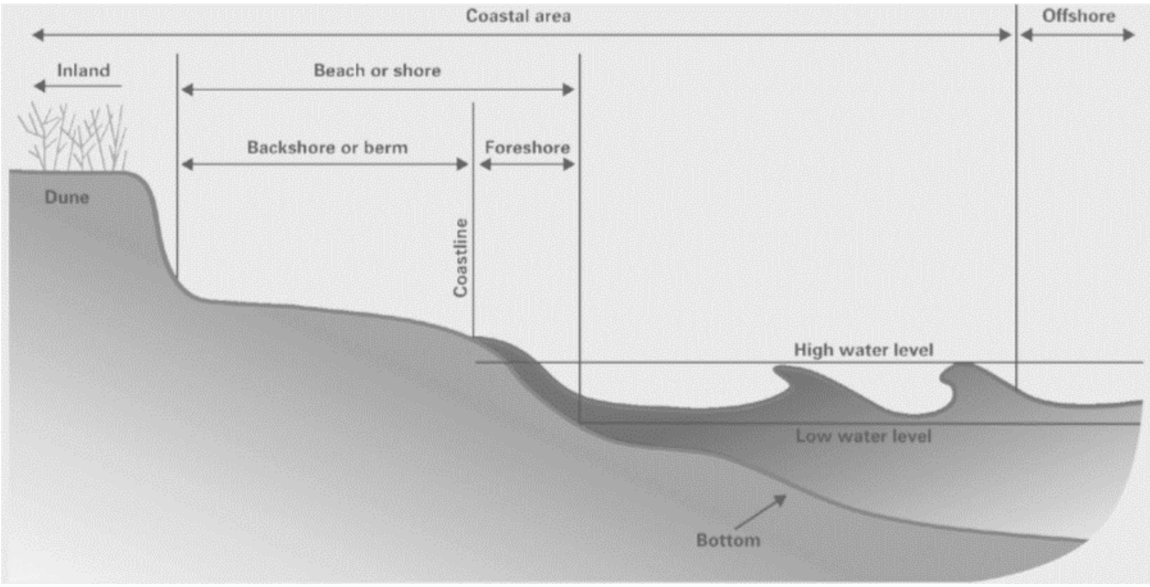

Figure 1. The Components of a Coastal Beach System [6].

1.2. *Research aim and objectives*

The aim of this research is to investigate the effectiveness of USACE beach fill construction projects and explore quality assurance procedures and processes associated with beach fill projects. Goals of research were established as follows:

- Determine the effectiveness of beach fills on storm damage reduction
- Determine the factors influencing the construction of beach fill projects
- Determine Quality Assurance processes/procedures
- Investigate benefits and risks from beach fill construction projects through state and federal employees

2. Literature review

2.1. *Overview*

A beach fill construction project consists of the placement of a large quantity of sand to a specified profile or design template. This template is authorized by congress to effectively reduce the threat of coastal storm damage on structures adjacent to the shoreline. These projects include an increase in the width and height of the beach or berm area and the construction of a sand dune placed landward of the sand berm. The dune is necessary to prevent damage from larger storm surges as these storms drive the sea level higher due to strong winds and pressure systems. The dune provides a significant quantity of sand higher than the berm elevation designed to dissipate the oceans wave energy when the forces of these waves threaten the coastal structures along the Atlantic [7]. The berm width can vary depending on the rate of erosion. However, the maximum authorized placement of sand is limited by the distance allowed by Congress [5].

Beach fill design template parameters are established for each project. Berm and dune elevations and widths are established. The design event is potential storm consequences that dictate the project design. For example, the West Shinnecock Inlet Project is designed for the 44-year storm event. This means the chance of a storm meeting or exceeding the design event is 1 in 44 in any given year. The Army Corps uses a cost benefit analysis to determine the dune height and width. The benefits are computed using the value of the structures that the dune is protecting. The costs are the full construction costs associated with completing the projects. To justify a project, the computed benefits divided by the construction costs must be above one. This is called the benefit to cost ratio.

Allocations of $500,000 were provided by Public Law 113-2 to complete a Performance Evaluation Report to evaluate the effectiveness of Army Corps projects during Hurricane Sandy and to include a compilation of recommendations for further improvements. They found six projects in the New York and New Jersey region experienced greater than a 200-year storm event. Eight projects experienced between a 30-year and a 200-year events. The projects were found to be effective in reducing storm damage with an estimated aversion of 1.9 billion dollars in loss. Report recommendations consisted of seven key strategies for further reducing damage risks due to these events. The following seven key strategies included:

- Employ a broader approach to project planning in these coastal regions
- Gather more data
- Use the Regional Sediment Transport to monitor the movement of material along the coast
- Develop Adaptive Management Plans to be implemented
- Address Back Bay flooding
- Evaluate the efficacy of dunes
- Incorporate a wider range of project benefits

Congress most recently passed an updated Water Resources Development Act which gives the Army Corps of Engineers the authorization to employ these engineered beach fill projects to a specified template with federal funding to reduce the impacts of super storms like Hurricane Sandy in October of 2012. The legislation allows for indefinite extension of beach fill projects, which demonstrates federal government support for beach fills as the most efficient and effective way of reducing coastal storm damage risk.

2.2. *Project hurdles*

Although the design of these projects may appear simple on paper, the Corps of Engineers has numerous hurdles to clear when executing the high dollar projects. Studies have been ongoing for decades to source sand from offshore borrow areas and the permitting process is very complex. The process of approval for borrow areas span several federal and state agencies to include the Department of the Interior, the Environmental Protection Agency, US National Marine Fisheries Service, US Fish and Wildlife, the National Oceanic and Atmospheric Administration and coordination with each state’s Fish and Gaming Agencies, Department of Environmental Protection, Water Quality Certifying Agencies and Coastal Zone Management Agencies to name a few [3].

Although some towns are very receptive to building more beach and dunes, other towns may object to the construction of the projects and the federal template because it may impede homeowner view of the ocean when gazing from the structures adjacent to the beach. Also, walking to the beach takes more energy to cross over the dune because it is constructed at a much higher elevation. Many residents complain of the steep slopes over the constructed dunes. Even when the community fully supports the beach fill project, individual homeowners can still disrupt the placement of sand.

Property boundaries for some beachfront properties extend to the beach and even to the waterline in some cases. This creates the need to secure real estate and easements prior to contract award. The real estate is required to prevent dunes far from the mainland which would leave it more vulnerable to erosion. The easement areas are necessary for accessing the beach with heavy construction equipment. Where shore areas are heavily populated, the price of real estate is often very high. If a project sponsor is unable to acquire the necessary real estate, easements, and staging areas, this can ultimately delay construction significantly. Eminent domain litigation may be required if cooperation from the home owners in certain areas cannot be secured. Once all the real estate is acquired, the US Army Corps of Engineers can award the beach fill construction contract to a dredging contractor available to dredge in the timeframe allocated for completion.

2.3. *Dredges*

There are two types of hydraulic dredge methods that can be utilized for these types of beach fills. The hopper dredge works by lowering drag arms down to the ocean floor and sucking up a sand slurry mix (approximately

30% sand / 70% water) from the designated borrow area by creating a vacuum in the ships large hoppers through mechanical pumps. Once the hopper is loaded with sand, it then navigates closer to sand placement point where there may be multiple discharge hookup locations with pipes leading to the beach. The proximity to the beach is dependent on the ships draft in the water.

A cutterhead pipeline dredge is the other type of hydraulic dredge often utilized to complete these beach fill projects. Instead of drag arms that lower to the bottom, there is a cutterhead arm. This cutterhead is a mechanical device that has rotating blades or teeth and is lowered to the ocean floor to swivel back and forth to cut through and suck up the sand. The sand is broken up by the blades and sucked through the intake pipe. The Cutterhead Dredge is connected to a floating pipeline which runs to the sands placement site so a continuous stream of sand slurry can flow.

2.4. *Studies*

Studies have been ongoing for decades to source sand from offshore borrow areas. Each borrow area is carefully studied for not only for environmental impacts, but also for the compatibility of the sand gradation to match the gradation where the sand is to be placed. Geotechnical engineers at the Army Corps study sand borings at each borrow area to ensure the correct gradation. Capacity of each borrow area must also be measured to ensure there is enough sand to supply the massive volumes of sand to be placed. Sediment transport studies are then required along the Atlantic Coast and the migration of sand over time due to the ocean currents [3].

Estimated volume to be added or removed is measured by comparing a proposed template to an existing hydrographic survey. These hydrographic surveys are crucial for establishing the largest definable feature of work for beach fill projects, which is the volume. Because this is a very specialized field of construction and the costs to operate may be extraordinary, there are only a limited amount of resources, or dredge ships, to complete these types of jobs. Many of the jobs require 10 to 15 nautical miles between borrow source and final placement area. This is when the price can become highly dependent on the dredge method.

2.5. *Munitions and explosives*

Quality Assurance for these projects by the Army Corps is uniquely challenging and has evolved in recent years due to the possibility of pumping Munitions and Explosives of Concern (MEC) onto the beach. MEC can be transported through the pipes with the sand slurry mix from the borrow area to the beach and poses a real threat to the safety of the construction workers and beach goers since there is a possibility of the explosives being live.

The Coastal Storm Damage Reduction Project in Surf City, NJ in 2008 spawned the need to screen the sediment intake and outfall to all future beach fill jobs in New Jersey and New York. During the environmental study of the borrow area, there was no evidence of MEC. There was no MEC found until after the first 1.6 miles of the 18 mile stretch was completed. Once MEC started to surface, the Army Corps was forced to close down the beach for public safety concerns. The Army Corps were also forced to screen the majority of sand that was pumped by using ¾ inch screens.

Total amount to screen the berm volume came to a total of 17.7 million dollars, which was almost three times the amount of the project cost itself. This project caused all future beach fill projects in New York and New Jersey to screen all the sand at the dredge pipe intake to one and a half inches, and also at the pipe outfall to ¾ inches. The specifications of each beach fill job now contain language about MEC procedures and new information about the borrow area. The borrow area for the Long Beach Island beach fill project is located in the vicinity of a known World War I dumping site for Discarded Military Munitions (DMM) [4].

3. Methodology

Qualitative research utilizing a random sample of 12 interviews was given to New Jersey State employees and U.S. Army Corps of Engineer (Federal) employees. Participants were asked to respond to questions regarding the beach fill project benefits and risks to the Town of long Beach Island and the State of New Jersey. In an effort to validate interviews, the participants also completed a survey that based on a numerical scale.

A survey was completed by each participant. Survey questions were then rated on scale. The scale was expressed numerically from one to ten on how beach fills are either beneficial or risky to the Town of Long Beach Island and the State of New Jersey. One (1) served as the least beneficial or least risky to the town and state and ten (10) served as extremely beneficial or extremely risky to the state.

Case study was completed with research questions based on the Long Beach Island (LBI), New Jersey, beach fill construction project. This specific Northeastern Region project, contracted by the USACE Philadelphia

District, covers twelve miles of beach. Nine Philadelphia District USACE employees and eight New Jersey state employees are tasked with completion of this undertaking.

4. Results and findings

4.1. *Benefits*

Forty-eight percent of interviewees responded with key words “increases protection, minimizes damages”, making this the most common theme among interviewees. The majority of the respondents described the project dunes as protection of life, beach, property, and infrastructure. Respondents referred back to Hurricane Sandy of 2012 and described communities with beach fill projects versus communities without the beach fill. Participants described the communities with the project to have far less damage when compared to the town without protective dunes. 21% of participants also felt the increase to the beach area served as a benefit, allowing more room for recreational activities. The same percentage of people (21%) who liked the idea of more recreational area, felt the elongated beach helped with flood reduction. Only 5% of participants felt the beach fill project actually provided security to residential and vacation homes, and increased tourism. When asked how they felt this project increased tourism, one respondent answered “more beach, more visitors.”

Benefits cited specific to the State of New Jersey were also reported. 44% of interviewees describe the biggest benefit to the State was the protection of tourism. Interviewees described the beaches to be a huge source of revenue, an economic driver and a multibillion dollar industry in New Jersey. 31% of participant’s described the beach fill project as protecting the states interests such as jobs, schools and state revenues. Less common themes consisted of saving the state from insurance claims, saving funding on state emergency services, and increased tourism due increased beach area.

4.2. *Risks*

The next question addressed risks to the Town of Long Beach Island. 29% of respondents felt safety was the biggest risk of the project to the town. The following safety risks were noted by the participants: hazardous materials on the berm, construction equipment on the beach, munitions and explosives from borrow areas, dangerous slope of beach as a result of the beach fill, and typical safety issues that come with any construction project (pedestrians, employees getting hurt). One anonymous interviewee stated “the new beach fill material has to be closely monitored for any foreign debris or hazardous materials. If there were to be an issue with the material placed on the beach, it could result in beach closures for an unspecified amount of time, resulting in loss tourism and loss local business which is a huge potential risk for the town.” This could be the said the same for munitions and explosives of concerns pumped on to the beach.

Costs and maintenance of the project were also common themes amongst participants of the interview. The federal government funds the initial project and then it could possibly become the responsibility of the town to maintain the project. If a storm hits and it is declared a national emergency by the President, the government will fund the project. If storm hits and it is not declared an emergency, then it is declared as cautionary. When these projects are declared cautionary, they are funded through a cost sharing between federal government funding (65%), state funding (10%) and the town funding (25%) of the project costs. The major cost risk to the town is if federal funding is not considered in the future for this project or the cost sharing agreement changes with political administrations, the full project costs could potentially be a burden of the town residents.

Many participants felt the same risks that applied to Town of Long Beach Island also applied to the State of New Jersey. One additional risk that participants felt the State encountered was wildlife and ecological concerns. The New Jersey State Department of Environmental Protection monitors specific wildlife and endangered species. It is the responsibility of the state to protect the natural habitat of these species. If it is discovered that the natural habitat is endangered during the construction of the beach fill, the construction site will be shut down, causing scheduling and (potential) financial delays.

5. Conclusion

The Atlantic coastline is forever evolving with the persistent pressure of hurricanes and other coastal storm surges. Hurricane Sandy is just one of the latest storms to dramatically reshape highly vulnerable areas. The sacrificial dune and berm constructed by the US Army Corps of Engineers in Long Beach Island, NJ seemed to withstand the forces of Hurricane Sandy. Twenty five miles north of Long Beach Island, there was a major breach in the barrier island town in Mantoloking, NJ. The difference in damages between the two very similar geographic locations is attributed to the effectiveness of protective dunes created by the beach fill projects.

Research supported the effectiveness of USACE beach fill construction projects. The construction template of the protective dune and sacrificial berm reduces damages to coastal structures. This research also provided the quality assurance procedures and processes to include construction safety, specification adherence, and removal of munitions and explosives of concern. The construction of the project spans multiple organizations starting with the Army Corps of Engineers. Once the borrow sources are identified and beaches designed, the plans and specifications can be awarded to one of the few contractors that specialize in this area of expertise.

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Use of Recycled Plastic Water Bottles in Concrete Blocks

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Abstract

The purpose of this study is to examine the possibility of using plastic bottles in concrete block. The plastic bottles were used to create voids at equal distance between them in the masonry units. Concrete was placed around each bottle to encase it in the masonry units. The study utilized 500-mL plastic bottles placed inside concrete masonry units and analyzed the compressive strength. The testing for compressive strength was determined according to the ASTM C140 standard. Results from this study were deemed reasonable due to the testing of concrete cylinders as a control of compressive strength for the concrete blocks from Oman's market. This study shows 57% improvement of strength by using plastic bottles compared to local concrete blocks. This proves the necessity for further research regarding concrete mix design, amount of cement and properties of local concrete blocks as well as other technical and non-technical aspects to determine the appropriate mix design and feasibility in the production industry.

Keywords: compressive strength, concrete, plastic bottles, recycled materials

1. Introduction

Concrete masonry unit or concrete block is an important and common member in building construction in Oman. Usage of plastic water bottles are increasing rapidly in Oman and this country is facing the challenge of overflowing of landfills and impacts of disposal of plastic water bottles. Moreover the plastic bottles can provide thermal insulation that can reduce the consumption of electricity for cooling which is highly important since Oman is subtropical dry hot desert climate. This research intends to study the possibility of using recycled plastic water bottles within the local concrete blocks for the purpose of building construction with the focus of verifying the compressive strength. Hollow concrete block is a significant kind of masonry units existing for the builders and its application for masonry construction is increasing continuously. (Ahmad et al, 2014) Hollow concrete blocks may be used, as alternatives to bricks and traditional stones in construction and buildings. Due to its smaller weight and ease of transfer compared to bricks. Moreover it provides an advantage of uniform quality as well as speeding in construction and the largest durability. On one hand economically, they are less expensive, and consume less cement and less involvement of laborers. In addition, they can be used, in different places. Such as the interior walls, exterior walls bearing, and columns, the compound walls, and retaining walls etc. (Maroliya, 2012) several researches completed particularly to study the compressive behavior of concrete blocks mixed with other materials, commencing with 'High-Performance Concrete Masonry-Block Mix Design' by Amiri et al. This research was conducted on concrete block masonry design in 1994. This study looked at 41 different kinds of concrete mix designs and assessed the compressive strength of concrete with different types of aggregates. Amiri et al study determined that use of a minimum void gradation and a maximum aggregate size 1/4 inch (6.4 mm) allow a high-performance of lightweight to reduce the cost of concrete masonry block . Chandrakeerthy investigated on four test methods concerning properties of cement blocks to study the relationship of variables and properties with compressive strength at 1991. Chandrakeethy's study suggests the implementation of one part cement to one part sand capping with plywood packing. Compressive behavior of concrete with vitrified soil aggregate was tested Palmquist et al by examination of 10 batches at four different coarse aggregate volume fractions with three

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different combinations of vitrified and natural coarse aggregates. Results show that compressive strength decreases when volume fraction of vitrified soil aggregate increases. (2001). Researches by Ahmad et al (2014) to compare masonry hollow concrete block and masonry brick and Maroliya (2012) on load carrying capacity of hollow concrete block masonry wall confirmed that the strength of hollow concrete block masonry wall is lower than brick masonry wall but the cost of construction of hollow concrete masonry wall is less. Stahl et al (2002) used recycled wood aggregate to prepare lightweight concrete masonry blocks and control the outcome to meet the conditions of ASTM C129.trial cylinders and blocks were tested and found to be complying with the standard in terms of weight, compressive strength and durability. However economic performance was not studied.

The idea of using plastic bottles in concrete building construction was originated by Andreas Froses in Eco-Tec in 2001 where PET bottles are installed within the walls along with mortars to shape a structure (Froese, 2014). The Engineers without Borders at Kansas State University have worked on a method to use plastic bottles in wall construction of concrete walls. These plastic bottles were installed horizontally with concrete as mortar between them and also in the sides. Further tests were conducted to examine the compressive strength of concrete masonry units with plastic bottle cores. Results of the tests according to ASTM C140 showed that compressive strength is reasonable however further studies suggested confirming the validity in developing countries (Wonderlich et al, 2014)

Oman is facing challenges with regards to solid waste management and recycling. Since potable water mains do not exist in Oman consuming bottled water is greatly common and therefore waste plastic bottles management is a major challenge. Moreover hollow concrete blocks are vastly used in building construction in and thermal insulation of walls is another challenge that is faced in the hot dry climate of Oman. Using plastic bottles inside hollow concrete blocks may a solution to some of the stated challenges. This study attempts to verify this method within the local concrete block products with the focus of testing the compressive strength for the purpose of initial validation of this method in Oman.

2. Methodology

The method of study designed for this research included tests for eight concrete blocks, seven concrete cylinders and six hollow concrete blocks from Oman’s market. In Each block eight plastic bottles (500ml) was positioned. Main purpose is to control the concrete masonry to meet the ASTM C140 requirements. The compressive strength test was conducted for three times. First test was after 7days, the second time after 14 days and the last after 28 days. Further on the compressive strength of cylinders, bottle blocks and hollow concrete markets were demonstrated.

3. Test Plan

Three concrete batches were prepared and two, two and three concrete cylinders were made from each in order to determine the compressive strength of concrete blocks without plastic bottles after 7, 14, and 28 days. Concrete blocks without plastic bottles were prepared from the same batches of concrete.

Simple Code	Number
CY-7 D	2
CY-14 D	2
CY-28 D	3

Table 1. Number of specimens and coding

4. Concrete Mix Design

Concrete cylinders were tested to determine the compressive strength and then for comparing of compressive strength with concrete blocks. The testing followed the *ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens* and for concrete design mix was followed *BS standard* as it shows in this table.

Materials for concrete mix design	Value
F_c	20 N/mm^2
Cement	Portland Cement
Defective	5%
Slump	50 mm
Fine aggregate size	0-5 mm
Coarse aggregate size	5-10 mm
W/C	0.65

Table 2 concrete mix design.

5. Concrete brick with plastic bottles

The size of concrete brick with plastic bottles that is using in this study is 200mm wide by 200mm high by 400mm long. The plastic bottles will create the voids in the brick around eight bottles horizontal (500 ml). This study followed the ASTM C140 *Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units* for doing the procedures of the test. The compressive strength test of the concrete blocks with plastic bottles was tested after one week, the second will be after 14 days and the last one will be after 28 days. Each concrete blocks had eight bottles and a space between each bottle was positioned. This makes sure that concrete will cover each bottle to give more strength. Also, wires were used within the arrangement to ensure that bottles will not change their positions during concreting process.

Sample Code	Number of Specimen	Number of plastic bottle(500 ml)
CB - 7 D	3	8
CB – 14 D	2	8
CB – 28 D	3	8

Table 3. number of specimens and coding

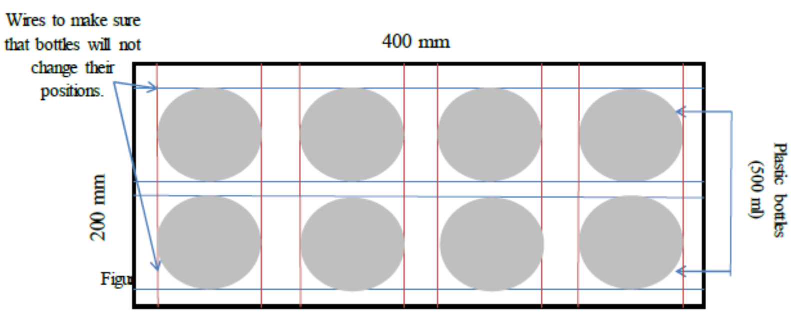

Figure 1 and 2.design of Concrete block with 8 plastic bottles (500ml)

6. Hollow Concrete Blocks from Oman's Construction market

The sizes of Hollow Concrete Block which is available in Oman's construction market (product of Oriental Insulated Block CO.L.L.C) Hollow Block is 200 X 200 X 400 with 20kg weight and eight specimen was used in the test to compare the compressive strength.

7. Compressive Strength test procedures

This test procedure was based on the ASTM C140 Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units procedure. For this procedure there are two loads that were needed to be determined. The ultimate / load, Pu, is and the estimated load, Pest.

8. Results

Test of Cylinder Strength				
Simple Code	Diameter(mm)	Area(mm^2)	Maximum Load(N)	Compressive Strength (Mpa)
CY-7D(1)	150	17671.459	185012	10.469
CY-7D(2)	150	17671.459	217554	12.311
CY-14D(1)	150	17671.459	432822	24.493
CY-14D(2)	150	17671.459	436630	24.708
CY-28D(1)	150	17671.459	459988	26.030
CY-28D(2)	150	17671.459	449915	25.460
CY-28D(3)	150	17671.459	455994	25.804

Table 4. Test Results from Cylinder Tests

Table 4 shows the results from the cylinder testing. The first batch was tested after 7 days for CY-7D (1) and CY-7D (2). The second batch tested after 14 days for CY-14D (1), CY-14D (2) and CY-14D (3). The last batch was tested after 28 days for CY-28D (1) and CY-28D (2). By measuring the diameter of the cylinder on the top surface or bottom surfaces determined the diameter which used to calculate the area for each cylinder. Maximum load is given by the Mastest (Compressive strength test Machine) for the ultimate load at which failure occurs. Maximum load is given with an accuracy of ± 1%. The compressive strength of each cylinder is determined by taking the maximum load of the cylinder and dividing it by the area of the cylinder. This compressive strength is then used to determine the estimated load of failure for the concrete masonry units. The compressive strength of cylinders between the 7 days and 14 days increase around 13 Mpa and the difference of compressive strength of cylinders between 14 days and 28 days around 1.2 Mpa.

Test of Concrete Block Strength			
Simple Code	Cross Area (mm^2)	Maximum Load (KN)	Gross Compressive Strength (Mpa)
CB-7D(1)	76000	458736	6.036
CB-7D(2)	76000	552520	7.270
CB-7D(3)	76000	584744	7.694
CB-14D(1)	76000	688138	9.054
CB-14D(2)	76000	748976	9.855
CB-28D(1)	76000	752400	9.900
CB-28D(2)	76000	760000	10.00
CB-28D(3)	76000	775200	10.20

Table 5. the results from the concrete masonry unit testing with plastic bottle cores.

The 8 specimens are used in 3 batches and each batch had different time. The first batch was after 7 days for CB-7D (1), CB-7D (2) and CB-7D (3). The second batch was tested after 14 days for CB-14D (1), CB-14D (2) and CB-14D (3). The last batch was tested after 28 days for CB-28D (1) and CB-28D (2). The gross area of the concrete block was determined in accordance with ASTM C140 standard. The dimension measurements were width and length of each specimen was used to determine the gross area. Maximum load for each block was determined from the same machine that used for cylinder testing. The maximum load is given with an accuracy of ± 1%. The compressive strength is determined by taking the maximum load of each block and dividing it by the area of each concrete block.

The above table reveals the difference between compressive strength of concrete block between 7 days and 14 days is about 2.5 Mpa, while the difference of compressive strength of concrete block between 14 days and 28 days is around 0.57 Mpa. There difference between the values of compressive strength of cylinder and values of compressive strength of concrete block id due to the different of cross area between the cylinder and concrete block.

Test Hollow Concrete Block from Oman's Market			
Simple Code	Cross Area (mm^2)	Maximum Load(KN)	Gross Compressive Strength(Mpa)
HCB-28(1)	74100	472410	6.375
HCB-28(2)	74100	523212	7.061
HCB-28(3)	74100	441870	5.963
HCB-28(4)	74100	385751	5.206
HCB-28(5)	74100	480027	6.478
HCB-28(6)	74100	535212	7.223

Table 6. Test results from Hollow Concrete Block

Table 6 shows the test results of hollow concrete blocks from the Oman's market. There were 6 specimens for one batch which was considered as after 28 days. The specimens labeled HCB-28(1) to HCB-28(6). The gross Area is determined by measuring the length and width of the block. The reading of maximum load is determined by the machine and its diagram that draw during the test. Gross compressive strength is determined by taking the maximum load value and dividing it by the gross Area.

Regarding the results above the difference between plastic bottled block after 28 days and the hollow concrete blocks which are from the market is about 3.64 Mpa and actually compressive strength in concrete blocks with plastic bottles increased by approximately 57% compared to hollow concrete block from market.

9. Conclusion

This study verifies the compressive study of plastic bottled concrete blocks used with local materials. The proximity of compressive strength and density between cylinder, bottled concrete blocks and hollow concrete blocks are acceptable. Moreover in comparison to Omani hollow concrete blocks the concrete blocks with plastic bottles shown 57% higher compressive strength. Further research on the other properties, economics and environmental benefits can be conducted to confirm the practice of using water bottles inside concrete blocks.

Acknowledgements

The authors would like to thank the management of civil engineering department in Middle East College, Dr.Anupam Sirvastav and Dr.Ram Kishore Manchiryal for their support and encouragement, the laboratory technician Mr.Yasir Balushi for his assistance in preparation of the materials and test process.

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Rutting Prediction of a Reinforced Cold Bituminous Emulsion Mixture Using Finite Element Modelling

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Abstract

A three-dimensional (3D) finite element (FE) model of a reinforced cold bituminous emulsion mixture (CBEM) was built in order to investigate the effect of static wheel load on rutting formation and flexible pavement response. This model has been developed to represent a four-layer pavement structure with elastic responses and to simulate the mechanical behaviour and pavement performance under static load condition. Also, it is focused on the prediction of the contribution of glass fibre (as a reinforcement material) in the surface course to develop the tensile and shear strength of flexible pavement. Preparation and validation of the model were carried out in the pavement laboratory using experimental data. In this research, finite element analyses have been conducted using ABAQUS software in which model dimensions, element types and meshing strategies are taken to achieve a desired degree of accuracy and convergence of the developed model. In addition, this developed model has been applied to CBEMs to investigate the effects of glass fibre on the performance of a reinforced pavement surface layer, as well as to study the effects of this fibre to minimize the vertical surface deflection, and horizontal and vertical displacements for the various courses. Finally, the FE model is capable of predicting surface damage to flexible pavement and its partial recovery after application of load. The results demonstrate the capability of the model in simulating the effect of fibre on vertical surface deflection (rutting), horizontal and vertical displacements in CBEM.

Keywords: ABAQUS, cold bitumen emulsion mixtures, rutting, three-dimensional finite element

1. Introduction

Permanent deformation (rutting) is one of the main important and significant damages encountered in flexible pavement, Permanent deformation (rutting) is one of the main important and significant damages encountered in flexible pavement, especially in the countries that have high temperature during the summer seasons. In all flexible pavement layers, the accumulation of permanent deformation under the effect of traffic loading causes rutting. Rut depth and width are mainly affected by structural properties of the pavement layers such as layers thickness, material quality, traffic loads and temperature [1]. The ability of rutting or permanent deformation prediction in flexible pavement is an essential part of pavement design. Therefore, some simplification hypotheses are often performed for analysis and design such as the elastic behaviour of pavement material and isotropic nature. The basic hypotheses of multi-layer pavement system include [2]:

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- Flexible pavement layers are homogeneous and isotropic.
- Materials behaviour is elastic and linear.
- Materials are massless.
- Layer thickness is limited.
- Load is uniformly distributed over a rectangular contact area.

Boundary conditions were considered that the contact between two layers is identical for both layers in term of shear tension, vertical tension, vertical and radial displacements.

Some diagrams and tables have determined stress, strain and displacement in multi-layer system after proposing these equations [3]. Finite element analysis is a numerical method to solve these equations.

The research objective is to develop a finite element model for an existing flexible pavement. This model would be capable of predicting the stress and strain responses of the elastic pavement and the output of the model is the prediction of permanent deformation (rutting).

2. Classical rutting prediction approach

Classic attempts to model rutting analysis are concentrated on protecting the under layers. At the top of the subgrade layer, the vertical stress and strain are limited to control the permanent deformation of the whole pavement structure and also restricted the tensile stress and strain at the bottom of the lowest bituminous layer to control fatigue cracks [4]. A classic model of rutting prediction utilized in road pavement analysis is given in [4] :

$$N_f = 1.077 \times 10^{18} \left(10^{-6} \div \varepsilon_v\right)^{4.4843} \tag{1}$$

Where:
Nf : applied load (kN).
εv : vertical compressive strain at the top of subgrade layer.

Nowadays, comprehensive researches have been carried out using different laboratory test methods such as wheel tracking test, creep test, complex (dynamic) modulus test and triaxial test, combined with contributions from investigations of pavement field rutting [4]. It was noticed that rutting failure was not solely occurring in subgrade layer or other under layers but also can be as a result of bituminous mixture problems. Consequently, it has become obvious that in accurate road pavement design procedure, the cumulative permanent deformation in all pavement layers must be considered.

Three model types have been used to compute permanent deformation in flexible pavement: empirical, mechanistic empirical and fully mechanistic. The empirical model is the simplest mathematical form fitted to controlled field data depending on regression equations. Properties of materials and site conditions are not included in this type of modelling whilst specific applications, for instance performance predictions in system of road pavement management are commonly used. The main purpose of this model is to evaluate future performance based only on the recorded deformation history.

The mechanistic empirical model is designed based on a combination of predictions of simple mechanistic response (usually using theory of elasticity) with empirical equations which are calibrated by experimental tests. The computed mechanistic response is utilized as input in the empirical model to predict actual performance, such as rutting and cracking. The effect of traffic loading and environmental conditions can be involved. Throughout application, the model mechanistic response is obtained during a pavement structural analysis. The linear elastic theory is usually used for its formulation and fast computer analysis.

Fully mechanistic models to compute or predict permanent deformation also use a structural analysis program to show the effect of the stresses and strains in the road pavement structure due to the influence of loading time (frequency) and temperature. The different characteristics of material behaviour are represented using constitutive models to directly predict rutting, cracking and other types of damage. With the most important points of these models, the effect of various load conditions, for example loading time, value and temperature can be simply evaluated and incorporated into these models. Because of capabilities of mechanistic models to predict road pavement distresses, there is no need for empirical functions. However, constitutive mechanistic models are complex and have some difficulties in calibration and execution. Very limited researches have been carried out to fulfil mechanistic models to predict behaviour of asphalt mixtures.

3. Materials and methods

3.1. *Materials*

The materials used in this research work are briefly introduced as follows:

3.1.1. Aggregate

A crushed granite aggregate both coarse and fine aggregate was used in this research which is normally used to produce Asphalt Concrete hot mix. The main properties of the aggregate together with the traditional mineral filler (limestone) used are presented in Table 1. The aggregate grading was asphalt concrete close graded surface course which is a prominent type of asphalt surface layer material, as shown in Figure 1 of mixtures (cold and hot) which are in accordance with BS EN 13108-1[5].

Table 1. Physical properties of the aggregate.

Properties	Value
Coarse aggregate:	
Bulk specific gravity (g/cm3)	2.78
Apparent specific gravity (g/cm3)	2.83
Water absorption (%)	0.6
Fine aggregate:	
Bulk specific gravity (g/cm3)	2.68
Apparent specific gravity (g/cm3)	2.71
Water absorption (%)	1.5

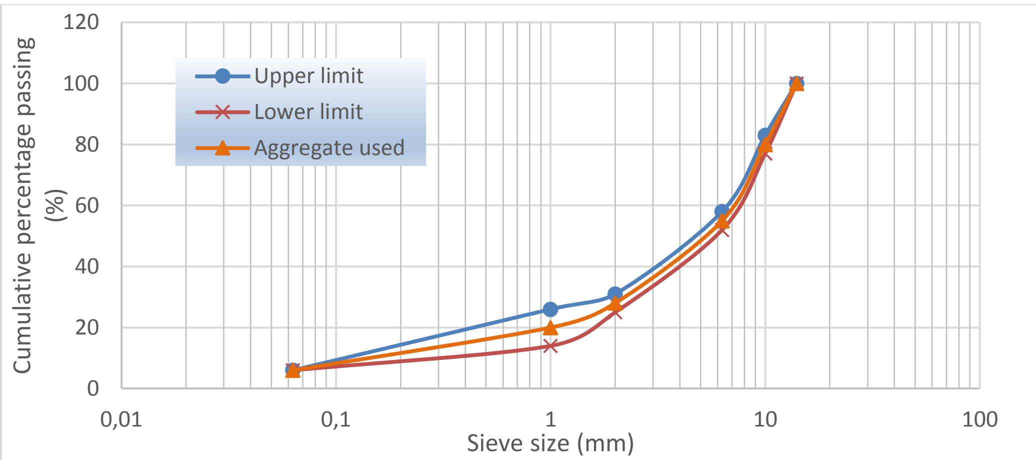

Figure 1. 14mm close graded surface course.

3.1.2. Bitumen emulsion and bitumen

A slow-setting cationic emulsion (cold asphalt binder (CAB50)) that contains 50% residual bitumen of 50/70 pen grade based bitumen was used throughout this study for the cold mixtures as its properties are shown in Table 2. This bitumen emulsion was chosen to obtain high adhesion between aggregate particles.

Table 2. Properties of (CAB50) bitumen emulsion.

Description	(CAB) bitumen emulsion
Type	Cationic
Appearance	Black to dark brown liquid
Base bitumen	50/70 pen
Bitumen content	50 %
Boiling point, ºC	100 ºC
Relative density at 15 ºC, g/ml	1.05

3.1.3. Filler and fibre

One filler type was used in this study, traditional mineral filler. Glass fibre was used in this study and it presents interesting properties as a reinforcing material. It is both strong and flexible. It is thermally and chemically stable at bituminous mixture temperatures of 200°C. It is not affected by de-icing salt, petroleum or bitumen. Glass fibre has a Young's modulus almost 20 times higher than typical bituminous modulus at around 20°C [6] and has a high tensile strength.

3.2. *Sample preparation and conditioning*

The design procedure followed the method adopted by the Asphalt Institute, (Marshall Method for Emulsified Asphalt Aggregate Cold Mixture Design (MS-14), 1989) for designing the cold asphalt mixtures. Incorporation of the fibre was achieved through partial substitution of the conventional aggregate. Glass fibre as a reinforcement material was the material that was added to the mixture. In order to find the optimum content and length of the glass fibre, cold bituminous emulsion mixtures (CBEMs) were treated according to fibre weight with 0.25, 0.35 and 0.50% of total aggregate weight and 10, 14 and 20 mm long. The testing results supported that 0.35% fibre content and 14 mm long gave the best results in term of Indirect Tensile Stiffness Modulus (ITSM). Compaction was carried out by means of a Marshall hammer with 50 blows applied to each face of the specimen. Cold mixtures are evolutional in nature, where the mixtures' strength characteristics are very sensitive to curing time and temperature.

3.3. *Method*

The fundamental test that was used is the Indirect Tensile Stiffness Modulus (ITSM): The test was conducted in accordance with BS EN 12697-26 [7], using Cooper Research Technology HYD 25 testing apparatus. The test conditions are as in Table 3.

Table 3. ITSM Test Conditions.

item	range
Specimen diameter mm	100 ± 3
Rise time	124 ± 4 ms
Transient peak horizontal deformation	5 µm
Loading time	3-300 s
Poisson's ratio	0.35
No. of conditioning plus	5
No. of test plus	5
Test temperature °C	20 ± 0.5
Specimen thickness mm	63± 3
compaction	Marshall 50×2
Specimen temp. conditioning	4hr before testing

4. Finite element modeling

After designing the conventional and reinforced CBEMs, stiffness modulus tests were carried out at two and seven days curing time as shown in Table 4.

Table 4. ITSM of the conventional mix.

Curing time (days)	ITSM (MPa)	
	Conventional	Reinforced
2	278	723
7	366	1060

4.1. *Model geometry*

The flexible pavement geometric model is created by using discrete parts which each part represent one structural pavement layer in the ABAQUS solid modeler. The geometric model is constructed in three dimensions (3D) finite element with a single axle which is assumed symmetrical on the surface of pavement in traffic direction. Model dimensions are used to avoid any edge effect errors, while having acceptable limits of elements' size.

Pavement cross-section is shown in Figure 2, four types of layers: cold bituminous emulsion mixture as a surface course, granular base, granular subbase and subgrade are performed to simulate the road pavement structure. All layers have the same shape to keep the nodes continuity between successive layers.

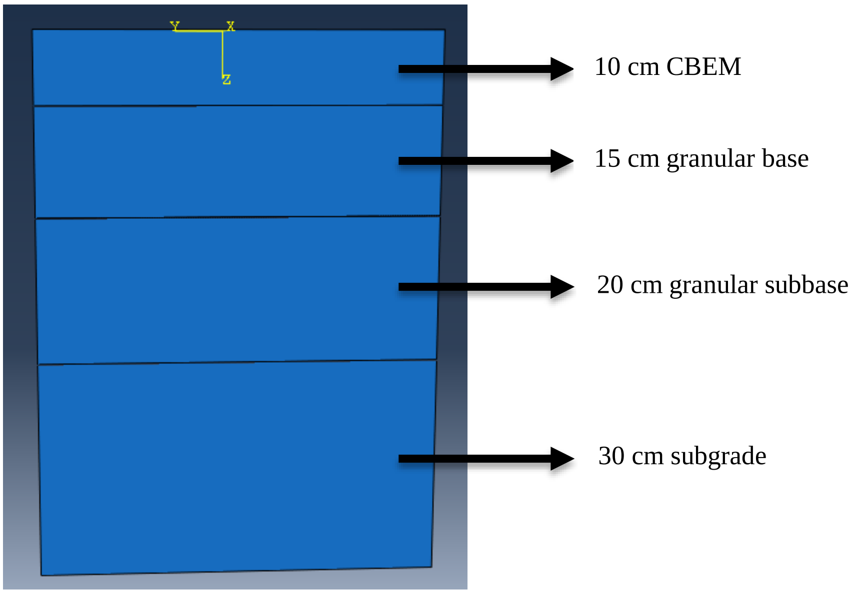

Figure 2 Pavement cross-section.

4.2. *Boundary condition*

Boundary conditions are employed to all edges or faces of the structural pavement geometric model to control displacement in the horizontal direction on the vertical edge which is perpendicular to the layer surface. The last layer (subgrade) modelling is assumed to be fixed with no displacement in horizontal and vertical directions representing a very stiff layer (encastre). The geometric model is symmetrical on x and y axes, therefore, quarter of the model is taken and the load is applied as shown in Figure 3.

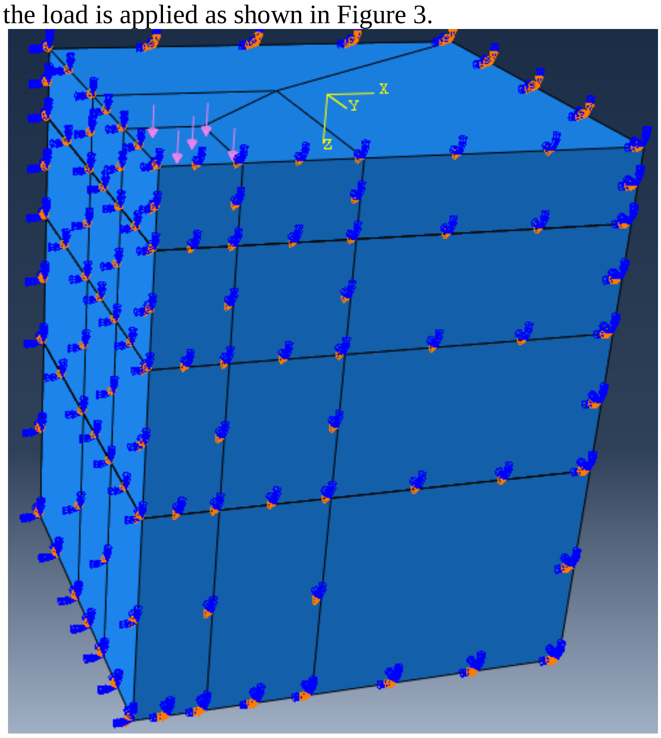

Figure 3. Boundary condition and load.

4.3. *Meshing and element definition*

The meshing process divides the body into many finite elements jointed at shared nodes. The accuracy of results depends on the density of the elements in a known area of the body. For instance, high density is preferred around the loading area and underneath the wheel path in the case of simulating a flexible pavement subjected to a tyre load, to improve the level of accuracy. However, computational time will be longer if more elements are there. It is significant to restrict the number of finite elements. In order to obtain asuitable mesh size, several iterations of finite element analyses are ideally performed with decreasing the element number for meshing a pavement structure. It will provide an adequately precise solution at a sufficient computational effort.

Through the mashing process, the element type and nodes number should be defined. Simple 8-node brick elements in three dimensional finite element model, which is selected to use in the analysis, or 4-node quadrilateral elements in two dimensions are allowing linear approximations of the movements between the corner nodes. Some elements have more nodes at the midpoint of each edge which will accommodate higher order approximating polynomials and the computational effort will increase significantly. Therefore, the most common way is utilizing simple finite elements and increase the density in areas of high preferred accuracy.

Figure 4 shows the plan view of the pavement surface. The tyre imprint area is modelled as a 29 x 20 mm rectangular area. The vertical and horizontal lines define the different meshing areas. The static load area is shown in the centre at which the most refined mesh is defined. All pavement layers are simulated with the same shape configuration. After completing zone configuration, a mesh study is carried out to find the optimal mesh density for each zone. Figure 5 shows the final mesh for the top surface layer. A denser mesh is employed in zones near to the load, whilst a relatively coarser mesh is used further away from the loading zones in both directions.

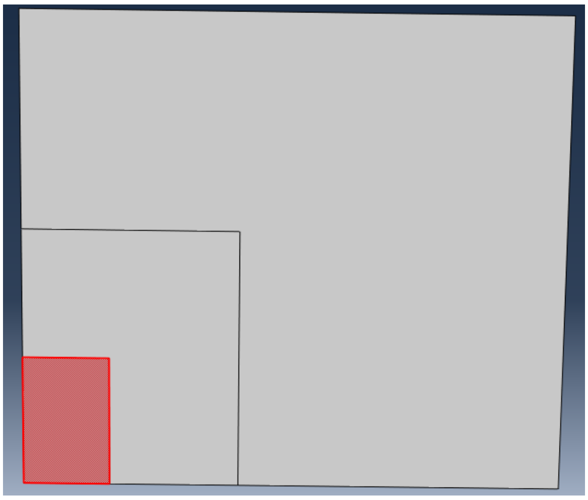

Figure 4. Pavement surface plan.

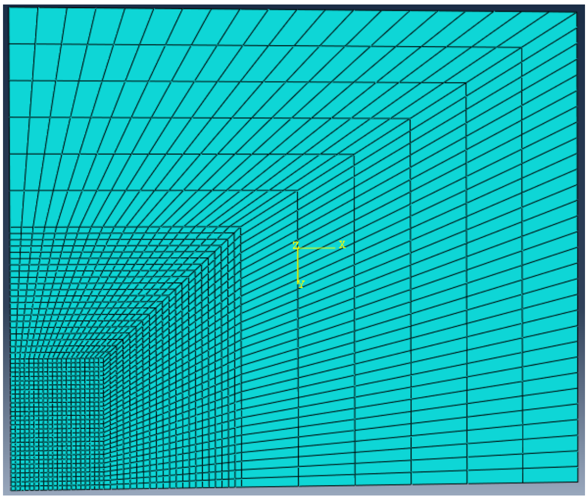

Figure 5. The final mesh of the top surface layer.

Each pavement structure layer is modelled individually as one part in the ABAQUS solid modeller. The same meshing processing by zones is used to the surface and under layers of pavement structure cross section shown in Figure 6. In order to determine a suitable element size to ensure a desired degree of accuracy and convergence for the developed model, several meshing iterations were used to reach the best and most accurate mesh size as shown in Figures 7 and 8.

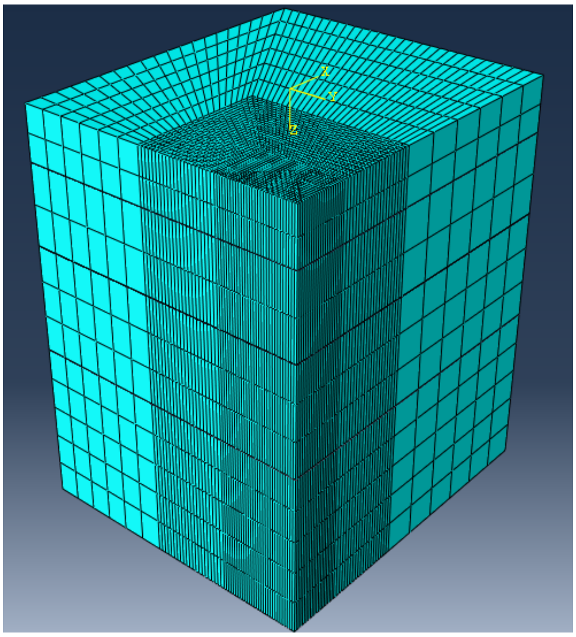

Figure 6. The final mesh of the pavement layers.

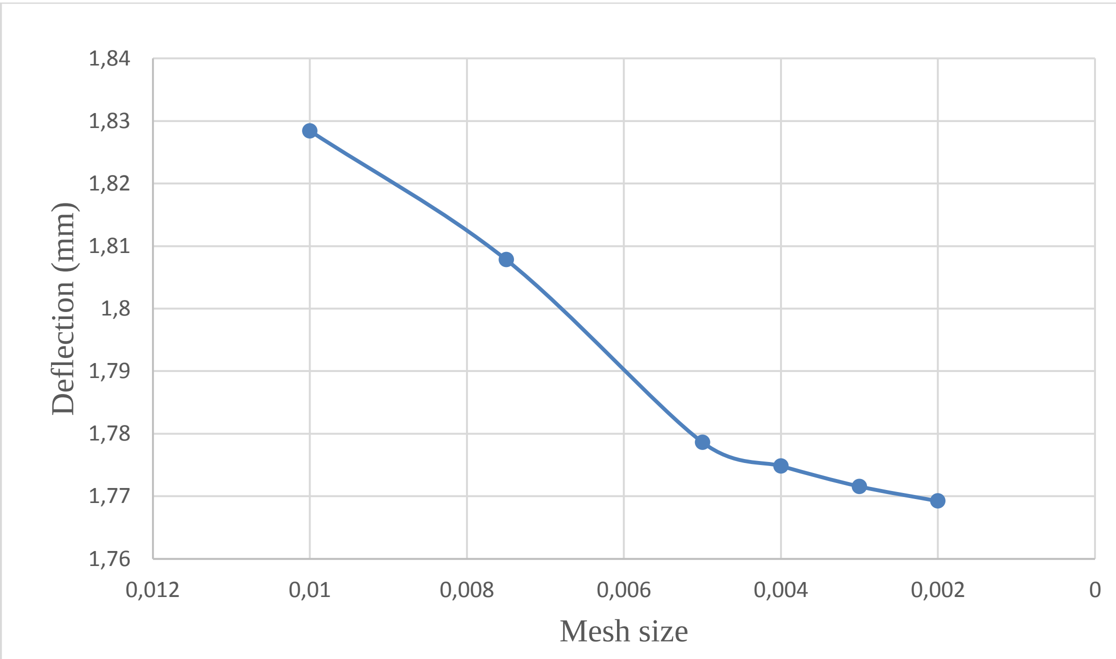

Figure 7. Mesh convergence of the finest area.

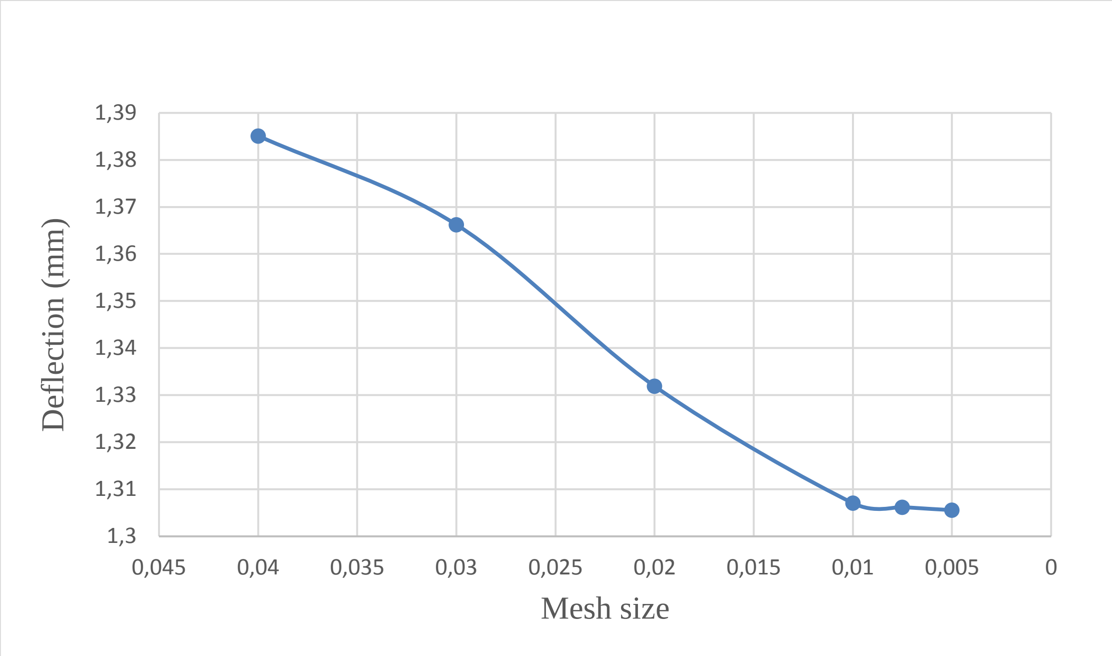

Figure 8. Mesh convergence of the middle area.

4.4. *Material properties*

In this stage of this report, all pavement material behaviours are modelled to be homogeneous isotropic linearly elastic responding to the applied load as static load. Experimental tests are carried out on CBEM after two days of curing as a conventional mix (without reinforcement) to obtain elastic properties of bituminous mixtures. The other layers are assumed granular base, granular subbase and subgrade and their properties were obtained from [8]. The elastic material properties are shown in Table 5.

Table 5. Elastic material properties.

Layer	Modulus of Elasticity (E) (MPa)	Poisson's ratio	Density (kg/m^3)
Surface	278	0.4	2200
Granular base	200	0.35	2000
Granular subbase	100	0.35	1800
Subgrade	50	0.3	1700

4.5. *Load application*

The prescribed applied load of the problem can be from forces, pressures or displacements for pavement structural analysis. In the loaded area, which is rectangular, pressure load is applied directly to the nodes and transformed into nodal forces as shown in Figure 3. In this report to simulate the static wheel load, a linear loading increment from zero to the maximum known value is performed.

Rahman, Mahmud [9] presents that tyre imprint area has to be a rectangular area which is more suitable than circular or ellipsoid tyre imprint areas. Also, this study shows that the tyre pressure is uniformly distributed over the contact area. The tyre imprint pressure load, which applied directly on the finite elements underneath the wheel path, is performed as 0.7 MPa (100 psi) which is to a single axial wheel load (40 KN) divided to the contact tyre footprint area (58000 mm^2).

5. Finite element simulation analysis

The parameters studied in this report are the vertical deflection of the pavement layers under the centre of the load and the vertical surface deflection (deformation) of the top of the surface layer (CBEM) in two dimensions. The top of the surface layer and the cross-sectional view of the pavement after applying the load are shown in

Figures 9 and 10 respectively. The pavement is symmetric with respect to x and y axes, therefore, one quarter of the pavement has been modelled to reduce analysis cost in terms of analysis running time, pre-processing effort and computer resources.

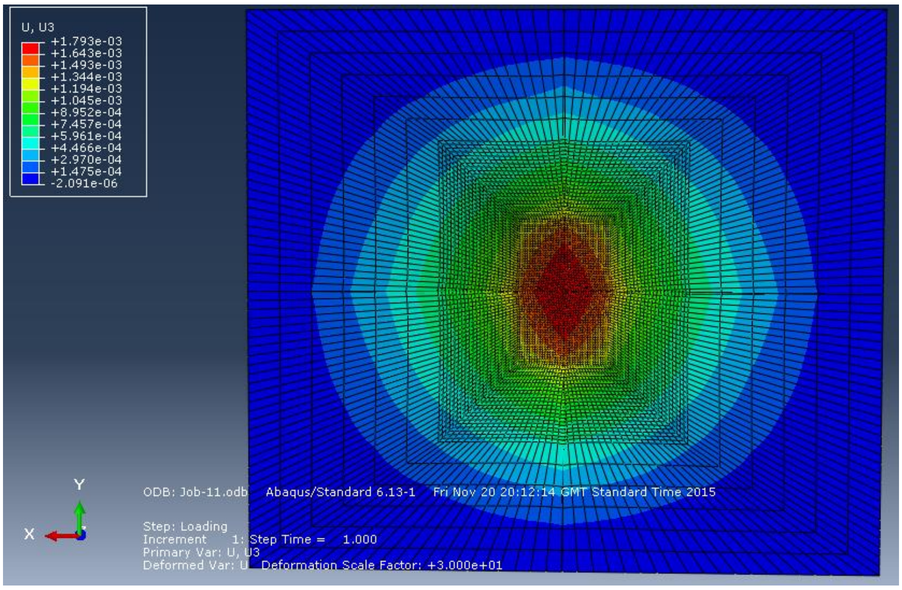

Figure 9. Top of the surface layer after applied load.

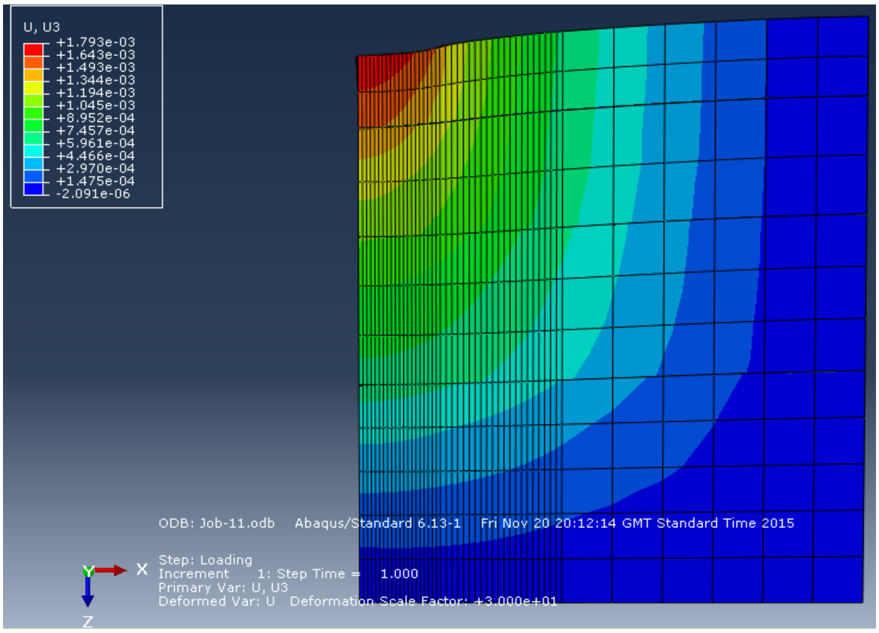

Figure 10. Cross-sectional view of pavement structure after applied load.

5.1. *Vertical deflection distribution*

The vertical deflection distribution along the pavement's cross-section for the unreinforced and reinforced pavement is extended along the bituminous layer, the granular base layer, the granular subbase layer and the subgrade layer. Two and seven days curing time were used in this report to obtain the strength of CBEM as a surface course. The vertical deflection distribution is changed when the surface layer strength increases as shown in Figures 11 to 14. The magnitude of maximum vertical deflection decreases when the magnitude of Modulus of elasticity increases. Figure 15 shows the vertical deflection variations between unreinforced and reinforced pavements with glass fibre during different curing times.

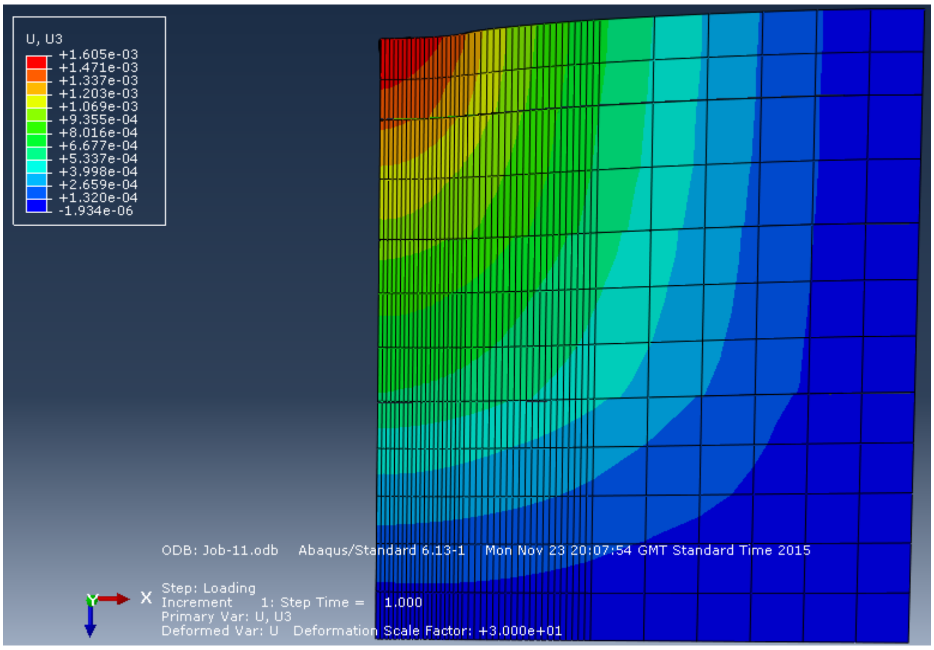

Figure 11. The vertical deflection distribution along the pavement's cross-section for the unreinforced pavement after 2 days curing.

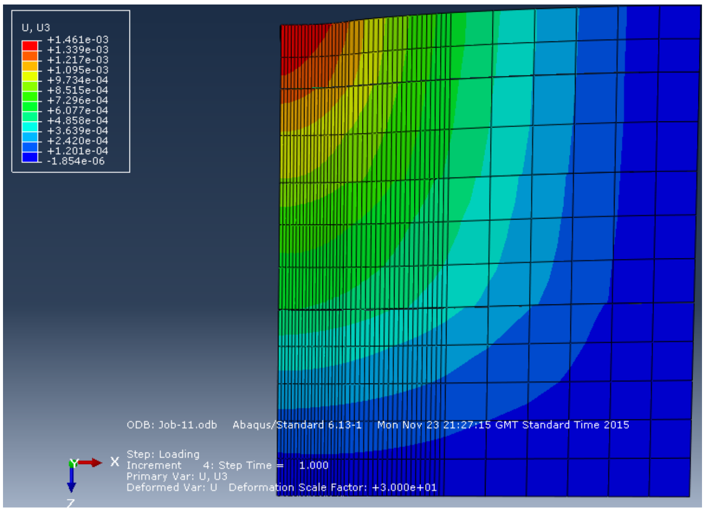

Figure 12. The vertical deflection distribution along the pavement's cross-section for the unreinforced pavement after 7 days curing.

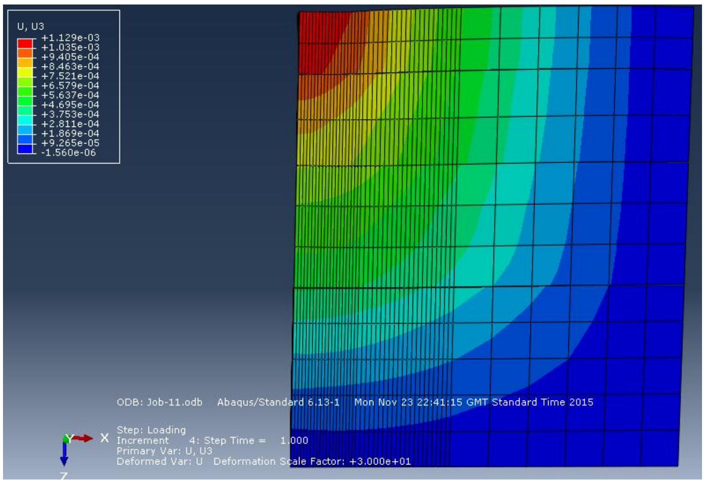

Figure 13. The vertical deflection distribution along the pavement's cross-section for the glass fibre reinforced pavement after 2 days curing.

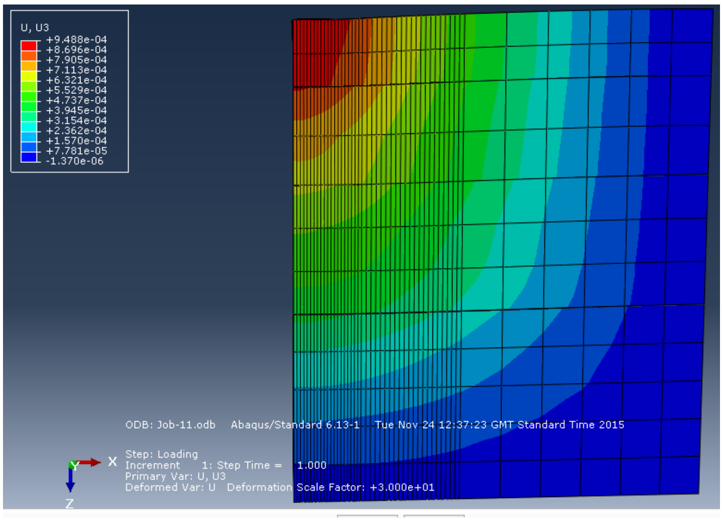

Figure 14. The vertical deflection distribution along the pavement's cross-section for the glass fibre reinforced pavement after 7 days curing.

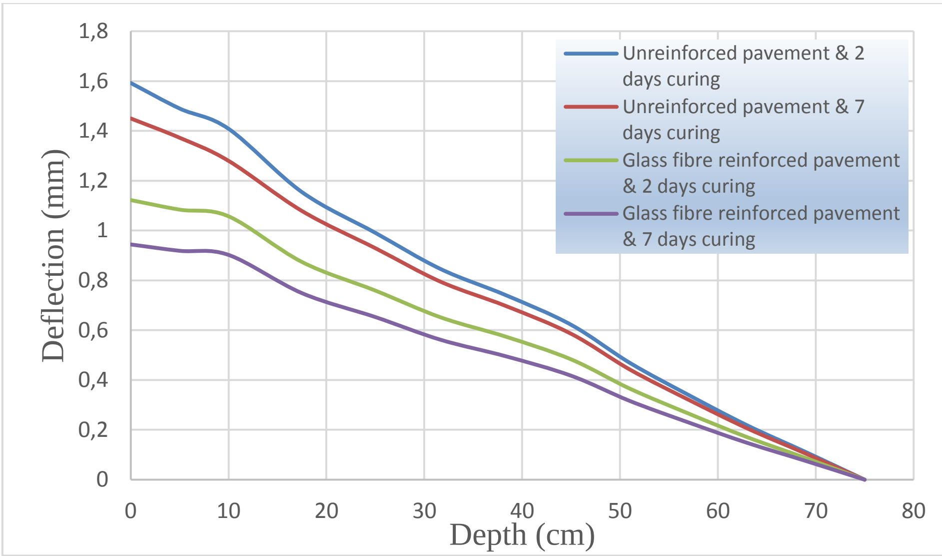

Figure 15. The vertical deflection variations between the unreinforced and reinforced pavement by glass fibre with different curing times.

6. Conclusion

It can be concluded that the highest reduction of the vertical deflection is achieved for pavement with 0.35% glass fibre after 7 days of curing time. This reduction, which reaches nearly 59%, is achieved when the stiffness modulus increased from 278 MPa for unreinforced pavement to 1060 MPa for pavement reinforced with glass fibre.

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Deterioration Patterns of Stone Claddings under Standard Conditions and Marine Environment

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Abstract

Building facades are exposed to degradation processes because of the direct exposure to various environmental impacts. Severe service conditions such as marine environment can drastically accelerate the deterioration of stone cladding. The objectives of the study were, as follows: exploring the typical deterioration patterns of the exterior natural stone cladding implemented by wet and dry fixing and estimating the predicted service life (PSL), in course of the exposure of cladding to the impact of the standard and marine environments. Although the dry fixed method has recently become highly ubiquitous in the modern building practice, no studies have yet investigated the effect of fixing technique on the durability and service life expectancy of cladding. The research method is based on a systematic evaluation of the visual and physical performance of the components during their life cycle. 87 data points were collected and classified by a type of cladding and the service conditions. Regression analysis and prediction intervals were used for statistical analysis. The results clearly indicate that the type of fixing technique plays a crucial role in the rate of stone cladding decay in both standard and marine environment. The results have also integrated the data provided by material scientists and geologists on the mechanisms of stone deterioration, as a function of stone type, service conditions and the effect of the contact between stone and the Portland cement mortar. It could be obviously observed that the PSL of the dry-fixed stone cladding is ~ 1.3 – 1.6 time more than in case of the wet fixed technique, in both standard and marine environment, with the upper limit of 60 year service life of the dry-fixed cladding exposed to the standard service conditions. This study provides useful information for designers, construction and facility management decision-makers and for effective planning of preventive maintenance plans.

Keywords: double skin facades; maintenance; marine environment; natural stone claddings; service life prediction.

1. Introduction

During their life cycle, exterior finishes of building facades are exposed to several environmental agents which cause the deterioration process starting as soon as the exterior finishes are implemented. Especially for the buildings located along the seashore, the degradation process can be drastically accelerated [1] because of the extremely aggressive offshore environment [2]. In fact, marine salt solutions penetrating the material can crystallize and cause high pressure resulting in cracking and spalling [3, 4].

Various types of the exterior finishes are used in the modern construction. Stone claddings are especially common thanks to their expected high durability. The method of stone fixing seems to play an important role in their long-term durability [4]. Dry fixing (Double Skin Facades) in natural stone claddings is a relatively new cladding method characterized by a cavity space between the facade layers. This fixing technique has nowadays become widely used worldwide thanks to their acoustic and energy efficiency [5], as well as their suitability for tall buildings. However, no studies have investigated the long term durability of cladding implemented by this technique. The main disadvantage is the much higher construction cost compared to the traditional wet fixed stone cladding.

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The current research follows the outlined methodologies set forth in previous studies implemented on renders, ceramic claddings and wet fixed stone cladding under standard service conditions [6 - 8].

2. Background

The Reference Service Life (RSL) of building components reflects the expected service life that a building or its components are expected to endure under a certain set of service conditions. ISO 15686-1 [9] has established the methodology for estimating RSL and this topic has attracted a growing interest worldwide as evidenced by the related international codes and regulations [10, 11].

Previous studies have reported the results of extensive fieldwork based on visual observations (empirical method) of the component performance of exterior finishes subjected to the different service conditions [8, 12]. In addition, during the last decade several studies were carried out using accelerated laboratory tests (minero-petrographic and chemical analyses; physical tests of porosity; hydric tests and durability; mechanical tests, etc.) [13, 14, 15], to simulate the natural weathering of stone claddings in standard conditions or marine environment. Although these studies provide some insight into the relationships between the micro-and macrostructure of stone and its deterioration, they are time and resource consuming. Consequently, statistical and probabilistic service life prediction methods provide a means to analyze the fieldwork collected data at different levels of complexity resulted from the concurrent analysis of multiple degradation factors [12, 16, 17].

Simple regression analysis has been used extensively to obtain the deterioration patterns that fit to the data points collected in the field, and to determine the average rate of degradation over time. The degradation level of each observed building component could be calculated as an average of the visual and physical performance values [6-7]. A prediction interval is used for the statistical evaluation of errors associated with the assessment of the predicted service life (PSL) of a building component at given age. Gaspar and de Brito [18], Galbusera [19], and Bordalo [20] made use of regression analysis. Silva et.al [21] examined the degradation process in 142 buildings with natural stone claddings directly adherent to the substrate.

Based on the same concept as simple regression analysis, multiple regression analysis enables the analysis of the relationship between more than two independent variables [22] as used by Silva et.al [12, 23], to predict the service life of building components. The report by Silva et al. [24], revealed the following variables to be responsible for the degradation of stone claddings: a) a distance of less than 5 km from the seashore was the most unfavorable; b) type of finishing: where a carved finishing was more prone to degradation than smooth and polished surfaces; and c) the size of the stone plates where larger stone plates were more vulnerable to mechanical deformation and, consequently, to degradation because of their larger dimensions and weight.

3. Objectives and Method

The objectives of the study were, as follows: exploring the typical deterioration patterns of the exterior natural stone cladding implemented by wet and dry fixing and estimating the predicted service life (PSL), in course of the exposure of cladding to the impact of the standard and marine environments. The research method is based on a systematic evaluation of the visual and physical performance of the components during their life cycle, based on the method described in [6 – 8].

3.1. Standard service conditions

The method used here for evaluation was developed in [6]. It is an empirical practice used for assessment of the degradation curve of building components and their consequent service life and is based on the direct observation of building components exposed to the same service conditions at different ages. The first step consists of the evaluation of the physical and aesthetical performance of building components according to systematic rating scales, as illustrated in Tables 1 and 2.

Table 2. Physical rating scale, Shohet and Paciuk [12]

Rating	Description of features
20	Significant portions of the cladding have peeled or fallen off. Cracks wider than 5mm have been developed.
40	Cracks wider than 1 mm have been developed on 5% or more of the cladding area. Portions of stone cladding have fallen off.
60	Cracks 0.5 mm wide cover less than 5% of the total cladding area. Up to 3 % of cladding elements have fallen off.
80	Capillary cracks have been developed on portions of cladding. Single cladding elements have fallen off.
100	Cladding is complete and undamaged. No cladding elements have fallen off. Some capillary cracking may be present.

Table 3. Visual rating scale, Shohet and Paciuk, [12]

Rating	Description of features
20	Significant portions of the cladding are missing or incomplete. Cracks have been developed on the cladding surface.
40	Damage is localized. Microorganisms have colonized over one third or more of the cladding.
60	Cladding surface is not uniform due to physical damage or discoloring.
80	Cladding surface is not uniform due to minor cracks, detached tiles, microorganisms or alterations in cladding color.
100	Cladding surface is undamaged and uniform (no visible cracks or missing elements and no discoloration).

This process gives a value for the component performance (CP) that ranges between 0 and 100 grading points, depending on the average of the aesthetic and physical performance state (100 = absence of any defect or failure, 40 = comprehensive failure). The performance score describes the symptomatic effects of deterioration caused by the interrelationship of several factors with the service conditions and the durability of the components. The typical deterioration patterns (TDP) of the building components can be derived by implementing regression analysis on the curve of the observed CP values plotted against the age of the building component used as the independent variable. These results represent the average degradation over time of the particular deterioration mechanism under analysis. Furthermore, the prediction interval enables an evaluation of the statistical errors associated with the assessment of the service life expectancy of future observations. The prediction intervals were established at 0.8 level of significance, as recommended by ISO 15686-1 (2011) [9].

Analysis of the typical deterioration patterns enables estimating the service life of building components at different levels of desired performance. The intercept between the typical deterioration patterns and a curve representing the minimum required component performance (MRCP) can be used to deduce the life expectancy (LE) [12]. Two levels of MRCP were considered [6, 7, 8, 23], as follows:

(1) MRCP = 60%, in cases where a high level of CP is required, i.e., in public or corporate buildings;
(2) MRCP = 40%, in cases where the owner of a building decides to minimize maintenance costs while compromising the quality.

It should be noted that this method is valid if only one specific agent of decay affects the building components. In order to calculate the life expectancy under exposure to multiple agents, this process must be reiterated for each of the deterioration mechanism studied.

The predicted service life interval (PSLI) is determined from the intercepts between the MRCP curve and the lower and upper boundaries of the computed prediction interval. This represents the time interval for which a (1-α) probability exists and a future life expectancy (LE) for the required CP can be established. In the same manner, the (1-α) predicted component performance interval (PCPI) can be deduced from the intersection between the component's age and the lower and upper boundaries of the computed prediction interval. In this case it reflects the possible error in predicting a future CP at a given service age.

3.2. Intensive service conditions

The standard service conditions determine the life cycle of building components subjected to normal weathering conditions without any severe aging hazards or intrinsic defects (e.g., poor quality of materials, faulty design, poor workmanship, etc.). The intensive and failure service conditions reflect the typical agents of deterioration, leading to premature degradation of exterior claddings. In this context, marine environment can be considered severe service conditions. This manuscript presents the typical deterioration path for the decay mechanism prevailing in marine environment, calculated for a sample of wet and dry-fixed stone claddings. The expected effect of this particular mechanism on the estimated service life of a building components (ESLC) can be estimated based on the life expectancy limited coefficient (LELC) [6,7,23], as presented in Eq.(1):

$$LELC = 1 - \left(\frac{SLE - LEDP}{SLE} \right) * IC \qquad (1)$$

Where,

LELC is the life expectancy limiting coefficient for the specific decay mechanism (for example, marine environment).

SLE is the standard life expectancy.

LEDP is the life expectancy of the deterioration path determined for the particular decay mechanism.

IC is the influence coefficient. IC values range between 0, for degradation agents that have no effect on the ESLC, and 1, for agents that have a strong impact. IC is determined empirically by experts. In the current study, where premature degradation was caused by an exposure to marine conditions, IC was taken to be 1, reflecting the high level of stone cladding vulnerability.

4. Results

Extensive fieldwork was performed in order to effectively model the evolution of stone cladding degradation over time. A total of 87 tall and high-rise (more than 4 floors) buildings with exterior stone claddings were graded and further categorized by the method of fixing technique and exterior service conditions. All the degradation paths of cladding techniques under analysis were found to fit linear patterns with different deterioration rates and regression coefficients, R^2, between 0.74 to 0.90, demonstrating a high level of significance. Three different scatter diagrams were carried out, as follows: (1) dry-fixed under standard conditions, (2) dry-fixed exposed to marine environment and (3) wet-fixed exposed to marine environment. The buildings in the sample exposed to marine conditions were located in close proximity to the seashore (less than 400 meters), taking into account the local breeze regime. Dry-fixed stone cladding is relatively new technique for external finishing in Israel, and has only been used on a large scale since approximately 1985. For this reason there is limited availability of data for this technique for buildings older than 30 years.

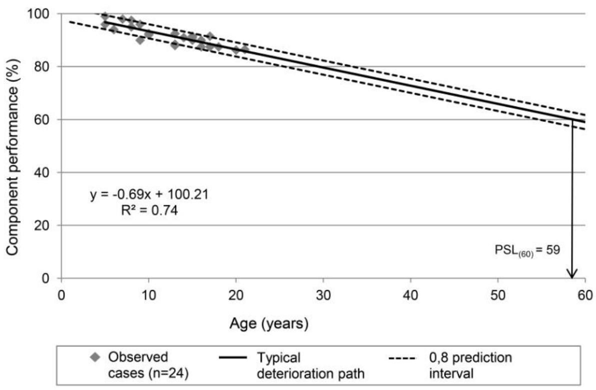

Figure 6. Deterioration pattern of wet-fixed stone cladding under standard conditions

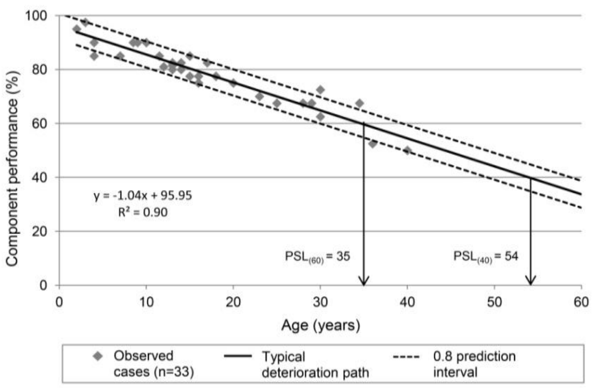

Figure 2. Deterioration pattern of wet-fixed stone cladding exposed to marine environment

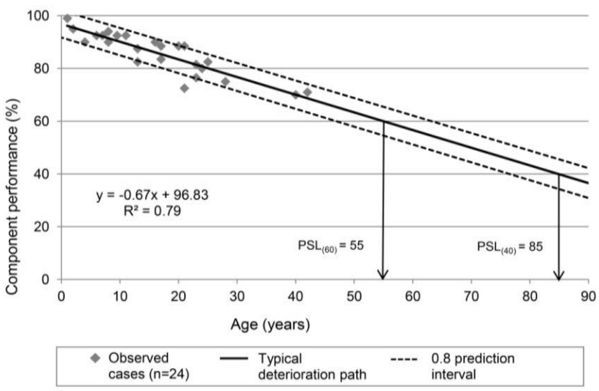

Figure 7.Deterioration patterns of dry-fixed stone claddings exposed marine environment

Table 3 summarizes the reference service life, PSLI and PCPI of wet- and dry-fixed stone claddings exposed to the different environmental conditions analyzed. It could be obviously observed that the PSL of the dry-fixed stone cladding is ~ 1.3 – 1.6 time more than in case of the wet fixed stone cladding, in both standard and marine environment, with the upper limit of 60 year service life of the dry-fixed cladding exposed to the standard service conditions.

Table 3. Predicted service life (PSL), Predicted service life interval (PSLI) and Predicted component performance interval (PCPI) of wet- and dry-fixed stone cladding

Service conditions	Wet-fixed		Dry-fixed	
	Standard	Marine environment	Standard	Marine environment
Predicted service life MRCP60%	44	35	59	55
Predicted service life MRCP40%	64	54	88	85
Predicted service life interval* MRCP60%	39 – 50	30– 40	55 – 63	47 – 63
Predicted service life interval* MRCP40%	59 – 70	49 – 59	84– 92	76 – 93
Predicted component performance interval*at life expectancy of MRCP60%	52– 69	55 – 65	57 – 63	55 – 66
Predicted component performance interval*at life expectancy of MRCP40%	32 – 49	35 – 45	38– 43	34 – 46

*p = 0.80 (p – statistical probability)

The LELCs concerning the impact of the marine environment on the predicted service life (PSL) of wet and dry-fixed stone claddings were, as follows: (1) 0.79 - 0.84 for the MRCP of 60% and 40%, respectively, for wet fixed technique, and (2) 0.94 – 0.97 for the MRCP of 60% and 40%, respectively, in case of the dry-fixed technique. These data reveal the main differences in the impact of marine environment on the performance of two fixing techniques under discussion.

Based on these results, the impact of the exposure environment can be calculated according to Eq. 2, as follows:

$$EF_{A-B} = \frac{1 - LELC_A}{1 - LELC_B} \qquad (2)$$

Where

EF_{A-B} – environmental factor coefficient for the two alternative fixing techniques *A* (Wet-fixed) and *B* (Dry-fixed).

$LELC_A$ and $LELC_B$ – Life Expectancy Limiting Coefficients for Wet and Dry-fixed stone claddings, respectively. According to the values of LELC abovementioned, EI_{A-B} for $MRCP_{60\%}$ and $MRCP_{40\%}$ are 3.5 and 5.3, respectively. These values indicate that the impact of a marine environment on deterioration of wet-fixed stone cladding is 3.5 to 5 times higher than on dry-fixed stone cladding.

5. Discussion and Conclusion

The results reported in Table 3 clearly indicate that the fixing technique had a strong effect on the rate of exterior cladding decay. Dry-fixed stone claddings were characterized by a longer service life under both standard conditions and marine environment. On the contrary, wet-fixed cladding, which had already manifested a higher rate of decay than the dry-fixed one in both environments, also showed a strong impact of marine environment on the predicted service life (PSL). These findings could be explained by the differences in the fixing technique of the stone to the background wall. The stainless steel anchors used in the dry-fixed technique are specially designed and controlled in the industrial manufacturing process. Therefore, they are able to improve the quality and reliability of the dry-fixed connection. Hard limestone, marble and granite used for the dry-fixed stone cladding, are characterized by low water absorption and are more resistant to marine environment than porous sedimentary stones [24]. The deterioration mechanism in wet-fixed stone cladding is mostly related to the effect of Portland cement mortar on stone. Natural stones are highly vulnerable to the impact of Portland cement mortars (PCM), which can be attributed to the high pH > 12 of the mortar and high humidity level maintained at the back surface of stone plates. These conditions lead to the formation of limonite (rust) crystals which cause opening of stone veins and, consequently, cracking of limestone and sandstone containing the secondary iron minerals [24]. High humidity levels behind the stones prevent the passage of air and lead to cycles of hygric expansion and shrinkage [*ibid*].

The current research contributes to a better understanding of the impact of marine environment on the performance of exterior stone claddings. The main causes of stone cladding deterioration were explored and quantified in years, in terms of Predicted Service Life. These results can be assimilated in maintenance planning and for decision making related to the design of single and double skinned stone facades.

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Multi-criteria Decision Making Tool for Technological Variants of Road Rehabilitation

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Abstract

Following the current trend of increasing buildings density, both residential and industrial, the need to strengthen and improve transport and engineering infrastructure has become essential. Despite the fact that both construction and continuous road and transport network reconstruction are vital elements in meeting the sector`s criteria, numerous bodies, whether it is a state or a regional government, face various obstacles in its implementation. Having said that, it is the aim of this paper to present a valid concept of the multi-criteria decision-making software application called OptiVote. This tool is able to recommend its users the most suitable method and technological option for flexible road rehabilitation project. The first part of this article introduces several calculation tools that allow to independently evaluate different methods of reconstruction. Those are the OptiRec family software tools, solving the traditional way of reconstruction (mill and replace) and the cold and hot recycling. Further on, a description of the wide range of technological alternatives for flexible road rehabilitation follows. The main part of this paper is devoted to a case study presenting a project implementation with three different rehabilitation technologies. Particular parameters such as the emission demands of each technology are being evaluated here by the OptiRec calculation tool. Those are the input data for the newly developed multi-criteria decision making tool OptiVote. Based on the selected criteria, user receives a clear recommendation, what method and technology to choose for a specific reconstruction. It is also possible to combine several user-selected criteria. For instance, price together with the environmental impact in proportion to the given recommendation or the user's choice.

Keywords: Multi-criteria tool; OptiRec; OptiVote; rehabilitation; road

1. Introduction

Each state, county and local government are struggling with on-going construction and rehabilitation of the road transportation network. Both activities are time-consuming, financially and resource-dependant. Its complexity depends on factors such as size and location, with also the available choice of project’s technological solution. Each project can be carried out not only by a basic technological method but also with its technological options.

Road management and maintenance are almost invariably entrusted to government authorities. This body, together with the design engineers take decisions about technological solutions of prepared projects. Based on their experience, knowledge and advice, the preferred solutions usually encompass traditional and time-tested ones. Such approach often brings along the fear of new or less conventional technologies, which may not be ideal. Especially as the choice of less conventional technological solution may be a cheaper alternative with regards to project costs, time and resources. We can therefore assume that a newly developed multi-criteria decision-making tool OptiVote could help change the situation described above. The tool offers a comprehensive solution not only for design engineers, but also to the road authority management.

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2. Available tools

Different financial resources and environmental demands of available road rehabilitation technologies lead to the search of useful tools that would help engineers and authority management in objective comparison of applicable solutions. Required evaluations must always respect the basic parameters of the solved project. OptiRec calculating tools comprehensively evaluates available technological methods. Each of the three methods listed below, including technological modifications represents one OptiRec software application. OptiVote tool evaluates the output data mainly from three described tools.

Basic methods for flexible pavement road rehabilitation:

- Traditional method (mill & replace)
- Cold Recycling
- Hot recycling

2.1. OptiRec TM

The TM software version primarily handles the rehabilitation of flexible pavement by the traditional "Mill and replace" technology. It is currently the industry standard and most common method of pavement reconstruction in the form of milling of required layers of a flexible pavement (most often the surfacing) and replacement thereof by new structural layers. The method is effective, however yet quite demanding particularly when it comes to material resources. As a consequence of cost savings in the field of rehabilitation together with the requirement for environment-friendly technologies, alternatives and equally effective solutions are being sought. E.g. the aforementioned cold recycling, hot recycling in-situ or a combination of both of the two methods available.

Traditional method technological variations:

1) Milling of selected layers of the existing structure and paving of new layers, virgin material
2) Milling of selected layers of the existing structure and paving of new layers, virgin material with 20 % and more of RAP added [1]

2.2. OptiRec CR

The OptiRec CR software tool handles primarily pavement reconstructions by detaching and mixing, applying cold recycling approaches, most frequently in-situ. It is also possible to prepare cold recycled material with special mobile mixing plant at a job site or at a dumping ground.

Cold recycling technological methods:

1) Milling of and mixing the material of existing structure of the selected layers (e.g. re-shaping)
2) Recycling with the application of hydraulic binders (R) – cement or cement suspension
3) Cold recycling (CR) in various variants using bituminous binder or a combination with hydraulic binder
   a. Bitumen emulsion
   b. Bitumen emulsion and cement (lime)
   c. Bitumen emulsion and cement suspension
   d. Foamed bitumen
   e. Foamed bitumen and cement (lime)
   f. Foamed bitumen and cement suspension [1]

2.3. OptiRec HR

The software tool OptiRec HR handles pavement rehabilitation by detaching and mixing, applying hot recycling approaches, most frequently in-situ. Recycling is carried out by a hot recycler (remixer) and a set of panel heating machines. The method is suitable particularly for reconstruction of asphalt wearing or binder course, in case that the lower structural layers are not violated. Due to the large size of recycler and heating machines, it is recommended to use the technology for road rehabilitation of larger dimensions and outside of residential areas.

Hot recycling technological variants:

1) Milling of and mixing the material carried out by in-situ hot remix plus technology
2) Milling of and mixing the material carried out by in-situ hot remix technology

3. Case study

For the case study, a road was chosen that requires reconstruction of the asphalt surfacing by one of the above-depicted technological options. This chapter aims to utilise the OptiRec applications in order to assess the selected reconstruction options. The choices are compared on the basis of the total CO_2 generated during the manufacturing of the materials incorporated (asphalt mixes, hydraulic binders and bituminous binders) and CO_2 produced by the machinery during the work completion as such. Apart from CO_2, other emissions of greenhouse gases (particularly NO_x, volatile hydrocarbons, CO, solid airborne particles) are being assessed as well. For the purposes of demonstrating the calculation tool results, a project with the following input parameters was selected (see Table 1).

3.2. Basic parameters

Table 1. Basic parameters of the road.

Type of road	Asphalt pavement (interurban)
Length of the section	1 000 m
Width of the rehabilitated road	10 m
Rehabilitation depth	120 mm (Mill & Fill)
	220 mm (Cold Recycling)
	50 mm (Hot Recycling) + 40 mm new wearing course

The road intended for reconstruction is a hypothetic example of a road with a minor traffic load. The end of the pavement surfacing life is indicated by defects like e.g. moderate deep cracking in the asphalt layers. The pavement surfacing consists of asphalt concrete of a total thickness of 120 mm. The base layer consists of a mechanically compacted aggregate layer being put on a protective layer from crushed gravel. The total thickness of the pavement structure is 350 mm.

Table 2. Basic fuel data. [2, 3]

Substance	Density (t/m^3)	CO_2 (kg/l)	Data source
Diesel – refining	0,84	0,26	Afteroilev
Diesel – consumption	0,84	2,66	MŽP ČR

3.3. Traditional way of rehabilitation

Within the framework of the traditional asphalt pavement reconstruction method, the whole thickness of both surfacing asphalt layers is supposed to be milled away. The base layer of the compacted aggregate is retained. A prerequisite for this is sufficient bearing capacity and flatness of the area. The milled material is transported to a dumping ground or a mixing plant (distance of 30 km). Subsequently, a paver lays two new structural asphalt layers ACbin 16 and ACsurf 11. The original vertical alignment of the pavement is retained. With respect to the nature of the reconstruction technology, the OptiRec MF calculation tool is used here.

Table 3. Traditional option for pavement reconstruction – pavement design.

Original pavement structure	Activities during the rehabilitation	New pavement structure
40 mm - ACsurf 11	Cold milling, paving	40 mm - ACsurf 11
80 mm – ACbin 16	Cold milling, paving	80 mm – ACbin 16
150 mm – Mechanically bond granular mat.	-	150 mm – Mechanically bond granular mat.
200 mm – Ga (31.5mm)	-	200 mm – Ga (31.5mm)

Table 4: Total released emissions on a hypothetical project (t). [4]

Used technology for rehabilitation	CO_2 (t) Material	CO_2 (t) Machines	CO_2 (t) Total	NOx + HC (t) Total	CO (t) Total	PM (t) Total
MF – traditional method	115,69	37,43	153,12	35,09	77,84	0,85

3.4. Cold in-place recycling

In the case of rehabilitation by application of cold recycling, the chosen technical option is a technology applying cation-active emulsion with residual bitumen content of 2.5 % and additional 1 % cement. A recycler performs in-situ recycling up to the thickness of 220 mm. Only asphalt wearing course must be milled off. The new asphalt layer ACbin 11 of a total thickness 50 mm is paved on the top of the cold recycled and compacted layer.

Table 5: Cold recycling – pavement design.

Original pavement structure	Activities during the rehabilitation	New pavement structure
40 mm - ACsurf 11	Cold milling, paving	40 mm - ACsurf 11
80 mm – ACbin 16	Cold recycling (in-situ)	220 mm – Cold recycled mix
150 mm – mechanically bond granular mat.	Cold recycling (in-situ)	200 mm – Ga (31.5mm)
200 mm – Ga (31.5mm)	-	

Table 6. Total released emissions on a hypothetical project (t). [5]

Used technology for rehabilitation	CO_2 (t) Material	CO_2 (t) Machines	CO_2 (t) Total	NOx + HC (t) Total	CO (t) Total	PM (t) Total
CR – bitumen emulsion, cement	150,25	22,89	173,13	86,05	83,11	2,41

3.5. Hot in-place recycling

When rehabilitating pavement structure by hot recycling - remix plus variant, existing wearing course is heated up into the depth of 50 mm. Subsequently, new aggregate and bitumen is added and mixed with existing material (hot recycling). The new wearing course ACsurf 8 of a total thickness of 40 mm is laid on the top of hot recycled layer.

Table 7. Hot recycling – pavement design. [6]

Original pavement structure	Activities during the rehabilitation	New pavement structure
-	Paving	40 mm - ACsurf 8
40 mm - ACsurf 11	Hot recycling (in-situ)	50 mm – Hot recycled mix
80 mm – ACbin 16	-	80 mm – ACbin 16
150 mm – Mech. bond granular mat.	-	150 mm – Mech. bond granular mat.
200 mm – Ga (31.5mm)	-	200 mm – Ga (31.5mm)

Table 8. Total released emissions on a hypothetical project (t). [6]

Used technology for rehabilitation	CO_2 (t) Material	CO_2 (t) Machines	CO_2 (t) Total	NOx + HC (t) Total	CO (t) Total	PM (t) Total
HR – remix plus technology	39,88	64,23	104,10	49,96	65,80	2,44

3.6. Summary

The table below contains an overview of applicable technological variants with a close focus on emission production during the rehabilitation process. This means the total quantity of CO_2, NO_x, volatile hydrocarbons, CO and solid particle matters generated during manufacturing of the materials are incorporated as well as the emissions resulting from the operation of construction machinery during the actual reconstruction. Greenhouse gas emissions released during production of building materials, their use, transport and fitting in structures counts to harmful and cause risk to the natural environment.

Table 9. Total released emissions on a hypothetical project – comparison (t). [4], [5], [6]

Rehabilitation technology	CO_2 (t)	NOx + HC (t)	CO (t)	PM (t)
Mill & Fill – traditional method	153,12	35,09	77,84	0,85
Cold recycling – bitumen emulsion, cement	173,13	86,05	83,11	2,41
Hot recycling – remix plus technology	104,10	49,96	65,80	2,44

Like the above-calculated values of the pollution load on the natural environment, OptiRec software tools provide also economic calculation, time and resource demands estimation of selected reconstruction options. Tools OptiRec thus constitutes the main source of input data for the newly developed OptiVote tool.

4. Decision tool

4.1. OptiVote

The newly developed assessment tool is a comprehensive tool aimed at road authorities and project architects. Based on the given parameters of the road and the subsequent election of preferred benchmarks such as impact on the environment or project cost, the user gets the best recommendation on pavement rehabilitation technology. The tool includes technological options of three basic reconstruction methods. Input data are calculated by software application OptiRec TM, CR and HR, eventually OptiRoad tool. Therefore it is possible to compare all available technological options of rehabilitation according to the selected criteria. In case they are combined together (multi-criteria evaluation), it is necessary to also set a weight rating among the criteria.

4.2. Evaluation criteria

The following criteria are divided according to their source, which provides input values for the multi-criteria evaluation:

- **Values from OptiRec:** 1 / environmental impact (produced CO_2, NO_x + HC, CO and PM); 2 / economic demands (cost of reconstruction); 3 / time demands (time of reconstruction); 4 / resources demands (material, mechanization, manpower - the quantity);
- **Values from OptiRoad:** 1/ life cycle costs; 2/ schedule or intensity of reconstructions throughout the life cycle
- **Values from other sources:** 1 / local availability of technology and resources; 2 / demands on the climatic conditions during reconstruction; 3 / impact on the environment during reconstruction (odour, noise, ...); 4 / applicability of the technology in various widths and inclinations of the road; 5 / technology trends that are used in the world; 6 / quality of the finished surface for vehicle (grip, noise, ...); 7 / safety in terms of operation; 8 / technology proneness to risk in terms of quality maintenance

4.3. Case study

The use of the OptiVote tool is presented on a case study where the main objective is to select the most suitable rehabilitation of asphalt pavement. This should be done according to the environmental impact (emissions generated during implementation and material manufacturing). The project is evaluated by three different technologies and the best option is recommended according to user-selected preferences.

Table 10. Multi-criterion evaluation - example. 1.

Criteria	CO_2	NO_x+HC	CO	PM	Score
Weight	10	60	20	10	100 %
Mill & Fill – traditional method	153,12	35,09	77,84	0,85	5201,9
Cold recycling – bitumen emulsion, cement	173,13	86,05	83,11	2,41	8580,6
Hot recycling – remix plus technology	104,1	49,96	65,8	2,44	5379,0

Depending on the user selected criteria and weights from the above (CO_2: 10%, NO_x + HC: 60%, CO: 20%, PM: 10%), the total score decides on the best suited rehabilitation method, whether it is a traditional method of rehabilitation, eventually hot recycling technology recommended for the project.

Table 11. Multi-criterion evaluation - example. 2.

Criteria	CO_2	NO_x+HC	CO	PM	Score
Weight	60	30	5	5	100 %
Mill & Fill – traditional method	153,12	35,09	77,84	0,85	10633,35
Cold recycling – bitumen emulsion, cement	173,13	86,05	83,11	2,41	13396,90
Hot recycling – remix plus technology	104,1	49,96	65,8	2,44	8086,00

If the user chooses the criteria and weights as in the Table 11 (CO_2: 60%, HC + NO_x: 30%, CO 5%, PM: 5%), recommended technology would be hot recycling or traditional method of reconstruction.

4.4. Summary

The case study above presents the way the tool OptiVote evaluates output data from OptiRec software tools. As an example for the illustration, there are only a limited number of criteria and technological options of rehabilitation being used. In a similar way, it is possible to evaluate other available rehabilitation technologies as well as to combine economical, time demanding and emission criteria.

Conclusion

The multi-criteria assessment tool OptiVote presents an effective tool in finding suitable technological methods for road reconstruction. The assessment principle is presented on evaluation of selected technologies, according to the environmental impact (emissions of harmful substances from the implementation - CO_2, NO_x, volatile hydrocarbons, CO and particulate airborne substances). The tool is used inter alia to support efficient way of investment and to introduce a more gentle approach to construction to the environment. Supported are both traditional methods as well as recycling technologies of reconstruction.

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Evaluating Barriers to Effective Implementation of Project Monitoring and Evaluation in the Ghanaian Construction Industry

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Abstract

Construction projects monitoring and evaluation is a vital process in the project delivery which is aimed at ensuring the major objectives and goals are achieved. However, the implementation of monitoring and evaluation in the Ghanaian construction industry have seen numerous challenges and as a result, the poor performance of the industry. This paper identifies and evaluates the barriers faced by projects in the implementation of monitoring and evaluation in the Ghanaian construction industry. Literature was reviewed and subsequently, a semi-structured questionnaire developed to stimulate the relevant response from the major stakeholders in the Ghanaian construction industry. The collected data were analysed using the one sample t-test. Literature revealed ten (10) challenging factors to the implementation of monitoring and evaluation. Weak institutional capacity, limited resources and budgetary allocations for monitoring & evaluation, weak linkage between planning, budgeting and monitoring & evaluation, weak demand for and utilisation of monitoring and evaluation results and finally, poor data quality, data gaps and inconsistencies were identified as the most significant contributing factors to the implementation of PM&E in Ghana construction projects. The study contributes to the body of knowledge on the challenges to effective monitoring and evaluation of construction projects.

Keywords: Construction industry stakeholders, Effective project implementation, Project monitoring and evaluation, Ghana.

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1. Introduction

The construction industry world over and more especially in developing nations are greatly manual and as such requires more human resource to undertake the many activities aimed at achieving set targets. These activities, however, require close supervision to ensure that they are executed right at first hand to eliminate re-work, increased project cost and prolong project duration and as such the need to monitor and evaluate projects to achieve the desired outcome. Project monitoring and evaluation, therefore, is a management function geared towards achieving effective use and efficient utilisation of project resources and as such cannot be overemphasized. Monitoring and evaluation are therefore critical to the performance of the construction industry and it seeks to facilitate strategic decision making to guarantee successful project implementation through a systematic and routine collection of project information and assessment of same [15]. Project monitoring and evaluation is explained to mean In spite of the effort made by project monitoring and evaluation teams (stakeholders) to achieve project objectives, problems with project delays, cost overruns, and non-conformity, as well as environmental issues, remains as yet unsolved. As early as the year 2000, [15] confirmed this inability of Third World and developing countries to successfully deliver projects but indicated the panacea to this challenge is the implementation of monitoring and evaluation.

Unfortunately, project monitoring and evaluation have been faced with numerous barriers to their implementation in the sub-region due to reasons such as the complex nature of construction and divergent views on project delivery with less technological integration in the industry in developing nations. The study, therefore, evaluates possible barriers and their dire/disastrous implications regarding the implementation of monitoring and evaluation in the Ghanaian construction industry. It is hoped that this study will provide an avenue for a more streamlined process for the reliable delivery of quality and economical projects within the stipulated time frame [4].

2. Literature review

2.1. *Barriers to the implementation of project monitoring and evaluation*

Worldwide projects have experienced numerous barriers in their implementation. As a solution, project monitoring and evaluation are key elements in improving project performance. These barriers are primarily influenced by the kinds of measures being used and the minimum amount of attention given to the practice. The effectiveness and success of every monitoring plan depend largely on the capacity of the institution or individual mandated to undertake the activity. Implementation of project monitoring and evaluation is therefore challenged with weak institutional capacity. Capacity building of institutions is relevant, not just for the immediate correction of poor performance, but also for the involvement based on a broad aim and result analysis [3]. Monitoring and evaluation are processes and therefore there is a need for synergy with other activities in the project cycle, such as planning and budgeting. Weak linkage between planning and budgeting on the one hand and project monitoring and evaluation on the other will adversely affect the ultimate aim of PM&E. An important consideration in planning for data collection and analysis is to identify any limitations, biases, and threats to the accuracy of the data and analysis [6]. It is also imperative to carefully plan for the data management of the M&E system which curtails time and resource wastage [6]. Budgeting for PM&E tasks and overall responsibilities must be listed and analyzed where necessary. Items associated with each task must be determined, including their cost, and there must be a budget for staffing, including full-time staff, external consultants, capacity building/training, and other human resource expenses. In addition, the budget should include all capital expenses, including facility costs, office equipment and supplies, travel and lodging, computer hardware and software, and other expenses. Budgeting must also determine whether all tasks are included in the overall project budget, such as support for an information management system, field transportation, vehicle maintenance, translation, and printing and publishing of M&E documents/tools. Poor linkage between these crucial steps in project monitoring and evaluation eventually poses a challenge [13].

The kind of measures used in measuring project monitoring and evaluation constrains the effective implementation of project monitoring and evaluation. [11] postulates that a problem with the various monitoring and evaluation models is that most of the measures are only capable of reporting on performance after they have occurred. According to [2], a conference of leading representatives from a group of design and construction companies noted that major problems with the key performance indicators (KPIs) of the Construction Best Practice Program (CBPP) were that they do not offer the opportunity to change and that they are designed as post-results KPIs. An examination of the other KPIs reveals a similar situation [5]. [2] explain two alternatives of KPIs as measures of assessment under "lagging" or "leading" measures: key performance outcomes (KPOs) and perception measures. KPOs could be used to assess a sub-process and give indications for change in the next sub-process. In this way, they could be considered as leading indicators [11].

Limited resources and budgetary allocations for PM&E, according to the GNDPC [10], pose a barrier to PM&E. Non-compliance with planning and PM&E guidelines, poor data quality, data gaps and inconsistencies are also factors facing PM&E in the Ghanaian construction industry. The absence of a comprehensive national database PM&E system and the development of PM&E objectives that are not measurable and therefore cannot be used to evaluate project performance and achievements or to communicate project results are barriers to the effective implementation of project monitoring and evaluation. Weak demand for and utilisation of PM&E data do not encourage the implementation of PM&E in the construction industry [6]. Finally, the development of a project monitoring and evaluation objectives which are not consistent with the needs and values of intended beneficiaries as well as projects activities that do not deliver the desired outcomes economically are further barriers confronting project monitoring and evaluation [10].

3. Research methodology

Literature revealed ten (10) barriers to the implementation of project monitoring and evaluation which underpinned this study. The factors were restructured for construction practitioners and stakeholders to rank them on a five-point Likert scale to help measure the strength and intensity of respondents' opinions of the identified challenging factors. The study took the form of a survey using a questionnaire. The research strategy adopted was qualitative and considered a review of literature to gain insight into the barriers to the implementation of project monitoring and evaluation practices in the Ghanaian construction industry. Forty (40) questionnaires were administered to monitoring and evaluation practitioners in nine (9) metropolitan/municipal/district assemblies (MMDAs) in the upper east region of Ghana through a purposive sampling technique. A one hundred percent response rate was achieved. Both desk and field survey data collection methods were employed. The desk survey (literature review) formed an essential aspect of the research since it set the pace for the identification of variables and the development of the questionnaire [8]. The field survey dealt with the administration and retrieval of the survey questionnaires.

In evaluating the results of the survey on the barriers faced during the implementation of project monitoring and evaluation in the Ghanaian construction industry, this research was interested in the significance of each barrier to the implementation of project monitoring and evaluation practices in Ghana. Hence, in establishing the significance of the variables, the one-sample t-test was used. The one sample t-test establishes whether a sample mean is significantly deviant from a hypothesised mean.

3.1. *Assumption*

The hypothesis for a single sample –test is typically set thus:

$$H_o: U=U_o \qquad \text{----------------} (1)$$

$$H_a: U<, >U_o \qquad \text{----------------} (2)$$

Where, H_o denotes the null hypothesis, H_a denotes the alternative hypothesis and U_o denotes the hypothesised or population mean. In a typical one-sample-test, the mean of the test group, degree of freedom for the test (which approximates the sample size), the t-value (which is an indication of the strength of the test) and the p-value (i.e. the probability value that the test is significant) are commonly reported (see for instance, [16]; [12]; [9]; [1]).

The mean for each barrier, including the associated standard deviation and standard error, is presented in Table 2. With each barrier, the null hypothesis was that the barrier factor was not critical (H_o: $U= U_o$) and the alternative hypothesis was that the factor was critical (H_a: $U>U_o$), where U_o is the population mean. Hence, U_o represents the critical rating above which the constraints are considered significant. For this endeavour, the rating scale adopted credited higher ratings of 4 and 5 to critical and very critical constraints, with U_o fixed at an appropriate level of 3.5.

The significance level was also set at 95 percent in accordance with orthodox risk levels [7]; [14]; [1]. That is, based on the five-point Likert scale rating, a barrier was deemed critical if it had a mean of 3.5 or more.

4. Data analysis and discussion

The top two (2) critical barriers to the implementation of project monitoring and evaluation are discussed. As can be seen in Table1, most barriers had a standard deviation of less than one (1), indicating there was agreed consistency in respondents' interpretations of these barriers. The standard error associated with all the means are relatively close to zero, suggesting that the sample chosen is an accurate reflection of the population. The fact that most variables had standard deviations less than one suggests that there were no differences as to how this variable was interpreted by the respondents.

4.1. *Weak institutional capacity*

This issue has bedevilled most activities in the country and most sectors of the economy, to be specific. Capacity building of institutions cannot be underestimated. It is no surprise that this variable occurred as the most critical challenge of project monitoring and evaluation implementation in the Ghanaian construction industry. This is probably attributed to the interpretations of the respondents as it recorded a low standard deviation of 0.736. Nonetheless, this indication shows that in Ghana much attention is drawn to the capacity and the impact of institutional efforts on most operations. Our institutions cannot easily adapt to new dimensions in the sector in which they operate as few of them undertake any research or continuous process development.

4.2. *Limited resources and budgetary allocations for monitoring and evaluation*

The second barrier to the implementation of monitoring and evaluation the Ghanaian construction industry is limited resources and budgetary allocations for PM&E. Cost overruns on projects in developing countries amount to approximately forty percent, making it difficult to prioritize those activities which are indeed necessary. The lack of investment in monitoring and evaluation is also on record, hence presenting the second critical barrier to the implementation of PM&E practices in Ghana.

4.3. *The development of PM&E objectives not consistent with the needs and values of intended beneficiaries*

Surprisingly, this barrier was ranked tenth (10^{th}). Although this could also be attributed to respondents' interpretations as it records a standard deviation of one, a probable reason is that in Ghana and most developing countries stakeholders rarely consider how project objectives are consistent with the needs and values of beneficiaries despite the increased demands for improved construction practices. Consequently, construction stakeholders are not keen on project monitoring and evaluation to suit the needs of the intended beneficiaries unless it is obligatory (i.e. deliberations by concerned citizens or social activists). It appears the practice is for these stakeholders to manage projects at their own expense, whereas the supervisory role of public agency has lost its control as there are huge breakdowns in communication amongst these stakeholders, as noted earlier.

Table 1: One-sample statistics

	N	Mean	Std. deviation	Std. error mean
Weak demand for and utilisation of monitoring and evaluation results	*40*	*4.13*	*.853*	*.135*
Weak institutional capacity	*40*	*4.55*	*.749*	*.118*
Weak linkage between planning, budgeting and monitoring and evaluation	*40*	*4.35*	*.834*	*.132*
Limited resources and budgetary allocations for monitoring and evaluation	*40*	*4.35*	*.736*	*.116*
Non-compliance with planning and monitoring and evaluation guidelines	*40*	*3.98*	*.800*	*.127*
Poor data quality, data gaps and inconsistencies	*40*	*3.98*	*.800*	*.127*
Absence of a comprehensive national database for monitoring and evaluation system	*40*	*3.70*	*.939*	*.148*
The development of monitoring and evaluation objectives that are not measurable and therefore cannot be used to evaluate project performance and achievements or to communicate project results	*40*	*3.70*	*.966*	*.153*
The development of monitoring and evaluation objectives that are not consistent with the needs and values of intended beneficiaries	*40*	*3.50*	*.987*	*.156*
Projects activities that do not deliver the desired outcome economically and do not have the desired impact	*40*	*3.93*	*.944*	*.149*

Table 2: Summary of t-test showing results of 1-tailed test and ranking

	Mean	Std. deviation	Ranking	Sig (1-tailed)
Weak demand for and utilisation of monitoring and evaluation results	*4.13*	*.853*	*4th*	*0.000*
Weak institutional capacity	*4.55*	*.749*	*1st*	*0.000*
Weak linkage between planning, budgeting and monitoring and evaluation	*4.35*	*.834*	*3rd*	*0.000*
Limited resources and budgetary allocations for monitoring and evaluation	*4.35*	*.736*	*2nd*	*0.000*
Non-compliance with planning and monitoring and evaluation guidelines	*3.98*	*.800*	*5th*	*0.001*
Poor data quality, data gaps and inconsistencies	*3.98*	*.800*	*5th*	*0.001*
Absence of a comprehensive national database PM&E system	*3.70*	*.939*	*8th*	*0.093*
The development of PM&E objectives that are not measurable and therefore cannot be used to evaluate project performance and achievements or to communicate project results	*3.70*	*.966*	*9th*	*0.099*
The development of PM&E objectives that are not consistent with the needs and values of intended beneficiaries	*3.50*	*.987*	*10th*	*0.500*
Projects activities that do not deliver the desired outcome economically and do not have the desired impact	*3.93*	*.944*	*7th*	*0.004*

5. Conclusion and Recommendation

In conclusion, the role of monitoring and evaluation in project implementation are enormous and as such must be given much attention by all stakeholders' undertaking key roles in ensuring health and safety compliance, achievement of project quality and delivery to project time as well as cost. In view of the effort to ensure that projects succeed, factors such as weak institutional capacity, limited resources and budgetary allocations for monitoring & evaluation, weak linkage between planning, budgeting and monitoring & evaluation, weak demand for and utilization of monitoring and evaluation results and poor data quality, data gaps and inconsistencies presented a challenge to project delivery in Ghana. It is therefore recommended that stakeholders involved monitoring and evaluation should undergo capacity building on strategies and new methods for effective monitoring and evaluation to guarantee projects success as well as allocation of funds for monitoring and evaluation.

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Human Resource Management Practices in Quantity Surveying Firms

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Abstract

It is vital for organizations to carefully design and implement the right mix of Human Resource Management (HRM) practices to achieve the desired result in terms of productivity and performance among members of staff. Literatures point to the fact that failure to understand and meet what staff expect and require from the organization will lead to deterioration in commitment and loyalty, stress, lack of motivated workforce and eventually, low productivity. This study therefore examined HRM practices in Nigerian quantity surveying firms. Various HRM practices in quantity surveying firms were assessed, taking a look specifically at staff strength, staff welfare, staff training, staff mentoring and succession. A total of 44 questionnaires were administered on quantity surveying firms in Lagos state, Nigeria using convenient sampling method. The study revealed that firms are not giving staff welfare and mentoring the expected attention, while the level of staff training is below average. It was recommended that quantity surveying firms should ensure proper recruitment and selection process, improve staff training, staff welfare, a strong/stable/increasing staff strength, staff mentoring and succession in order to enhance productivity and performance of the firms. There is therefore a need for quantity surveying firms to be active in the management of their human resources, as this will enhance their innovation and competitiveness in both local and international market.

Keywords: Human Resource Management (HRM); Mentoring, Nigeria; Quantity surveying firms; Quantity surveyors.

1. Introduction

Human resources management is fast becoming an important aspect of most organizational development. Qureshi *et al.* (2007) argued that the study of human resource management practices can be seen as a determining factor for organizational enhancement and staff performance. Business dictionary (2015) defines human resource management as the process of hiring and developing staffs so that they can become more valuable to the organization. According to Ayanda, Lawal and Ben-Bernard (2014) human resources management can be seen as the procedures and practices needed to carry out the human resource aspect of a management position, including selection, job definition, training, performance appraisal, compensation, career planning and encouraging employee participation in decision making as well as mentoring the staff to rise to the point of becoming partners or directors. Human resource management can therefore be seen as a determining factor for a firm growth and its knowledge, a powerful tool for a firm competitiveness and firm innovation practices.

Quantity surveying firms are some oriented organizations that provide services that cover all aspects of procurement, contractual and project cost management in infrastructural development. Sonia (2005) points out that knowledge management processes interaction in quantity surveying firms has become a powerful tool for sustaining firms' competitiveness and robust innovation practices. However in Nigerian today, there is a decline in human resource management aspect of most quantity surveying firms as more attention is given to the financial aspect of the organization that the development of staffs. Francis, Cyril and Samuel (2011) observed that the inefficiency of manpower, lack of performance evaluation, human relation problem which may include planning management, management not based on established merit, lack of technological experience, remuneration and motivation might hinder the performance of staffs in Nigerian quantity surveying firms. The management of increased workforce might create new problems and challenges as the workers are becoming more conscious of their rights.

Adrian, Stewart and Keith (2009) observed that human resource management has the complicated responsibility of balancing the needs and interests of staffs against the needs and interests of the firm. Normala (2006) posited that human resource management faces a lot of problems because of the continuous changing socio-economic, technological and political condition, management of labour, based on this. Thus it is important for human resource managers in quantity surveying firms to update themselves due to the changes in their environment and as well as in the management of staffs and the firm. It is in view of this that this research was carried out to examine human resource management practices in quantity surveying firms with a view to achieve human resource productivity. In achieving this stated aim the extent of staff welfare and the various staff training activities in quantity surveying firms was examined and the various ways of staff mentoring and succession in quantity surveying firms were identified and assessed.

2. Literature Review

2.1 Human Resources Management

The development of human resource management can be traced to the Industrial Revolution in England in the late eighteenth century though it was not labelled human resource management (Loosemore, Dianti, and Lingard, 2003). The economic and political conditions prevalent after the Second World War increased the demand for labour and personnel specialists to lead this era of Human Resource Management, viewing staffs as resources. These conditions which lead to the era of human resource management was due to the fact that the second world war has just ended, so people were urgently needed to work in factories etc. hence specialists were contacted so as to ensure good human resource management practices (Agbodjah, 2008). Normala (2006) observed that the concept of Human Resource Management became prevalent in the early 80s, there have been increasing academic interest in the concept as well as research in the area of human resource management.

Today the human resource management concept is concerned with the management of what most researchers describes as an establishment's most valued assets, the people within it in order to provide a competitive advantage (Agbodjah, 2008). According to Armstrong (2003) the main features of human resource management includes: emphasis on the strategic management of people (the human capital of the organization) which achieves 'fit' or integration between the business and the human resource management approach; a comprehensive and logical approach to the provision of mutually supporting employment policies and practices; the development of integrated human resource policies and practices (configuration or bundling); the importance placed on gaining commitment to the organization's mission and values; and the treatment of people as assets rather than costs. Walton (1985) believed that, staffs share the same interests as the firm's principle of mutuality rather than that these interests will not necessarily coincide; the performance and delivery of human resource management as a line management responsibility.

According to Fitz-enz (2000), staffs of a given firm are seen as what economist describe as what is called "human capital" because of how they add to the productivity of the firm and by virtue of the role they participate in the firm. He added that the human resource is the 'most bothersome of assets to manage'. Apart from achieving high performance through people which advocates for appropriate integration of people and processes (Becker, Huselid, Pickus, & Spratt, 1997), appropriate Human Resource Management is also seen to enhance motivation, commitment and job engagements (Agbodjah, 2008).

2.2 Human Resources Management Practices in Quantity Surveying Firms in Nigeria

The origins of quantity surveyors can be traced back to the ancient Egyptian civilization who used dedicated personnel to carry out estimates and costing for their magnificent structures and buildings. It developed into an occupation during the 17th century restoration of London after the Great Fire (Ilias, shafie and Abdelnaser, 2010). In 1836 the profession entered its new age when the new Houses of Parliament of Great Britain, designed by Sir Charles Barry, became the first major public contract to be fully measured and tendered using detailed bills of quantities for financial accountability (RICS, 2005). Then came early in twentieth century when the Royal Institute of Chartered Surveyors (RICS) London developed the early modalities of becoming a quantity surveyor which later gained global recognition. Foreign members later established similar professional bodies in their countries. One of these is the Nigerian Institute of Quantity Surveyors (NIQS) (Ilias *et al.,* 2010). The NIQS was founded in 1969 as a parallel body to the Royal Institute of Chartered Surveyors (RICS) of United Kingdom. In 1986, the Federal Government recognized the NIQS through the Quantity Surveyors Registration Board of Nigeria (QSRBN) decree No. 31 of December 1986. Chief Osuigwe Nwogu is recorded as the first Nigerian qualified quantity surveyor (Onwusonye, 2013).

In general, the principal services that could be offered by any quantity surveying firms are: preliminary cost advice and feasibility estimates, cost planning, advising on contractual methods, advising on selection of other consultants, advising on contractor selection, preparing tender documents, obtaining or negotiating tenders, reporting on tenders received or package deal/design and build offers, evaluating construction work, preparing and agreeing accounts for/with contractors, preparing expenditure statements for tax accounting purposes, periodic financial reporting, technical auditing, assessing replacement value for insurance, project management related services, giving expert evidence in arbitrations, adjudications and legal disputes, preparing/defending against construction contract claims (Ilias *et al.,* 2010).

The challenge to the management of quantity surveying firms is not only to focus on devising strategies for driving performance but to ensure sustainability by giving consideration to influences on implemented performance strives (Olanipekun, Aje and Abiola, 2013). Human resource management as a social phenomenon has therefore been affirmed as enhancing and sustaining performance of an organization and its staffs when its practices are rightly utilized. Quantity surveying firms can be more efficient and achieve sustainable performance if they focus their attention on those human resource elements/practices such as staff welfare, staff training and development, staff mentoring and succession so as to enhance their performance as well as increase their staff strength and staff performance.

3. Research Methodology

This study set out to examine the human resources management practices in quantity surveying firms. A survey design was adopted and questionnaires were distributed to quantity surveying firms in Lagos State, Nigeria. Since the total population of these firms is 57 (NIQS, Lagos chapter, 2013), census sampling was used. Various factors of human resource management practices such as staff strength, staff welfare, staff training, as well as mentoring and succession were considered.

4. Results and Discussion

4.1. *Characteristics of the respondents*

A total of 44 questionnaires were retrieved out of the 57 distributed. The analysis of data gathered showed that about 32% of the firms sampled have below 10 years working experience, while a larger percentage (68%) have above 10 years working experience, thus response from them can be relied upon due to this vast years of experiences of these firms. Their ownership status revealed that 55% are sole proprietorship, 41% are partnership while the remaining 4% are consortium. Result also shows that 32% of the sampled quantity surveying firms are involved in mainly building works while 68% are involved in both building and civil engineering works.

4.2. *Human Resource Management*

Result revealed that indicates that almost half of the quantity surveying firms (48%) does not have department responsible for human relations issue, while 30% have and 22% are not sure of the existence of such in their firm. Also about 16% of the firms that have a department that is responsible for human relations actual named such department as Human Resource Management and this department is responsible for the productivity of the staff and the firm. The remaining 14% have various names for this department. Result further shows that 19% of the firms have this human relations department managed by either the managing director, personnel manager or the general manager, while about 11% are headed by Human resource manager which indicates that human resource manager are rarely employed by quantity surveying firms so as to oversee the human relations of the firm.

4.3. *Staff Strength*

Result showed that the total number of overall staff strength in a quantity surveying firm has an average of 14.14 which is on a high side considering the number of firms under survey. Also the average number of industrial training students is 7.14, while graduate/probationer has an average number of 5.76. For registered staffs for both NIQS and QSRBN, the average number of staffs is put at 5.5 and this is considered to be very low. Also about 55% of the respondents believe that skills of staff is the main criteria through which Qs firms determines their strength of their staffs, while 36% and 9% believe ability and talent are the main criteria.

4.4. *Staff Welfare*

On staff welfare provided by quantity surveying firms for their staffs, result reveal that the adequate payment of staffs' salaries in quantity surveying firms is on a high side with more than half of the firms (64%) indicating that is very adequate, 32% indicated that it is adequate and only 4% indicated that it is inadequate. For staff pay increment less than half of the firms (43%) indicated that it is satisfactory, while the rest 57% believe it is not. This implies that quantity surveying firms increases salaries of their staffs only when necessary. Also 46% have no idea if their firm matches their pay with performance, while 18% and 36% indicate yes and no respectively. This implies that in most cases the workers are not carried along during the decision making that concerns their welfare.

On the support provided by quantity surveying firms for their members of staff, it was observed reward and incentives given to staff is not encouraging as 48% of the respondents affirmed that reward and incentive are given once in a while, 25% believe it is given sometimes while 27% claimed it is never given. Also 44% of the respondents have no idea if their reward is linked with their performance, while the number of respondents that stated yes and no were 28% each. In terms of staff health/medical insurance, 43% of the respondents believe it does not come often while 34% claim it is often and 22% believe it is not given at all. However the performance of transportation allowance is better as 46% believe it is given often, 14% believe it is given sometimes and 40% believe it is not.

4.5. *Staff Training*

Result revealed that 55% of quantity surveying firms assess their staffs based on performance appraisal so as to provide for their training needs, 14% of quantity surveying firms said that the training needs of their staffs are not assessed based on their performance appraisal while 32% of quantity surveying firms had no idea. Also 41% of quantity surveying firms provide social training for their staffs once in a while, also 32% of quantity surveying firms sometimes provide a training environment for the socialization of their staffs, while 23% never carry out such training for their member staffs. Also indicates that 41% of quantity surveying firms sometimes provide training for the general problem solving skills of their staffs which in turn brings about productivity from the staff and affect the firm positively, while 30% provide such training once in a while and 16% does carry out such training often.

Result further shows that 50% of quantity surveying firms never provide for professional training of their staffs within or outside the country which is on a high side, leaving 21% of quantity surveying firms to send their staff within or outside the country on a professional training, 11% of quantity surveying firms carry bout such professional training within or outside the country very often, while 9% and 7% respectively send their staff out for professional training sometimes and often. Also 34% of quantity surveying firms provide training for their staff for the broader knowledge of the firm aims and objectives sometimes, while 32% once in a while provide training for the broader knowledge for the firm aims and objectives, 14% never provide for such training and 18% of quantity surveying firms often provide for the training of their staffs for the broader knowledge of the firm aims and objectives.

4.6. *Staff Mentoring and Succession in Quantity Surveying Firms*

On opportunity available for staffs to rise to the position of partners and directors in the firm, 50% of the respondents believe that yes there is an opportunity for staffs to rise to the level of partner or director in their firm while remaining 50% believe such opportunity does not exist in their firms. However, it was observed that more than half of quantity surveying firms does not have any staff that rose to become partners or directors of the firm, while less than one third of staff that rose to become partners or directors of the firm, less than one quarter of firms had 3-4 numbers of staff that rose to become partners or directors, an average of 0.96 staffs has ever rose to become partners which is very low. Also more than half of the firms agree that mentoring offers benefits to the mentor, mentee and the firm.

4.7. *Discussion of Findings*

The questionnaire use for this research was used to assess the human resource management practice in quantity surveying firms operating in Lagos state, Nigeria. The findings look at the objectives of this survey which are; staff strength, staff welfare, staff training sand mentoring and succession as they are carried out in quantity surveying firms. With respect to the analysis carried out in the previous sections, the results indicates that staff strength of quantity surveying firms is below average as staffs tend to seek opportunities elsewhere due to the fact that their needs are not met by the firm. Anakwe (2002) in a study of human resource management practices in Nigeria found that traditional human resource management functions, are very much practiced by human resource professionals which seems to be missing in half of the firms under survey.

The training of staffs in quantity surveying firms is on the average as some firms provide training in areas such as social training skills, general problem solving skills training, professional training and training for the broader knowledge of the firm aims and objectives, seminars, workshops, etc. According to the observation of Aliyu (2011), staffs in quantity surveying firms are poorly trained, resulting to inability to retain specialist knowledge and potentials there by weakening the strength of the firm. According to Chris (2011) training of staffs can be done by measuring the extent to which trainees have applied what they have learnt from the training on their job, this can be effective if the staffs are subjected to some training as his view is contrary to the survey carried out on staff training in quantity surveying firms. Training programmes increases the firm specificity of staff skills, which, in turn, increases staff productivity and reduces job dissatisfaction that results in staff turnover (Huselid, 1995). But the findings prove otherwise as Qs firms rarely send their staffs to such training programs their by lowering the outcome of the staff which will later come to hunt the firm.

According to Staff welfare (2013) staff welfare is an all-encompassing term covering a wide range of facilities that are essential for the well-being of a staff offered by an employer/firm. From the research most quantity surveying firms pay their staffs adequately so as to make them feel secured with a satisfactory pay increase, but majority of these firms don't match pay with performance as this won't make the staff competitive and productive.

It was discovered that quantity surveying firms once in a while distribute rewards/incentives as this might depends on the financial strength of the firm, as some firms does link their rewards to staff performance. In the area of health/medical insurance, welfare packages are sometimes provided by some firms, they also often provide transportation/allowances, housing and occurrences such as accident. Also, quite a number of quantity surveying firms did not have procurement manager and lawyers on their pay-roll as this will cost more if these professional are been contracted outside during a given project.

Linney (1999) opined that succession involves identifying staffs within an organization who possess the skills necessary to move into positions of greater responsibility. Mentoring offers benefits to both the Mentor and Mentee**.** But based on the analysis staffs in quantity surveying firms rarely rise to become partners or directors, while some firms are saying that there are opportunity available for staffs to rise to the level of partners or directors, while some other firms are saying that there are no opportunity for such rise.

Generally it can be observed that quantity surveying firms are less aware of the fact that human resource management is a fundamental key to firm growth and sustainability, productivity and stability, there by shying away from its practices such as staff welfare, staff training, staff mentoring and succession, as well as why the staff strength of this firms are dwindling year after year, as staffs tends to look elsewhere for a better job security just because quantity surveying firm cannot provide you with such assurance of a secured job. The influence of human resource on firm's performance was not rated well from the research, meaning that management have to focus more on ways of improving human resource to bring about a great output of work from staffs and in turn enhance the overall performance of the firm.

5. Conclusion and Recommendation

The fact that there is an improvement in the level of staff performance is not indicative of an effective staff management system. The issue is that the staff manage to put in their best because of the fear of not getting a better job elsewhere, irrespective of the fact that they are denied some of the basic conditions and benefits which will improve their work life and enhance the firm's productivity as they lack the right motivation. Some staff management practices such as; appraisal, finance, prospects for promotion/succession, incentives/awards, health/medical insurance, transportation allowance, housing allowance, occurrences such as accident etc. will hinder the productivity on the performance of the quantity surveying firms and the staff. To ensure that staffs perform their jobs effectively, quantity surveying firms should ensure that the selection and recruitment process of staffs should ensure that skills, abilities, aptitude and other traits of the staffs are known and available. This process reduces turnover rate and dissatisfaction of the staffs and improves staff performance and productivity. **S**taff strength of most quantity surveying firms seems to be fairly adequate there is need to actually develop a benchmark as to the size and mix of categories of quantity surveyor for firms based on their age and nature of business.

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Attitudes of Owners which Impedes Firm's Growth: A Case of Small and Medium-Sized Construction Firms in Ghana

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Abstract

Owners of small and medium-sized construction firms are mainly classified as individual, group of people or institution ownership. Attitudes of owners who operate these firms do impact positively or negatively towards the growth of their businesses. This study sought to identify the specific attitudes of owners of construction small and medium size (SMEs) firms that impede growth. Interview with selected construction SMEs owners via snowball sampling was adopted in order to achieve the purpose of the study. Data was analyzed using descriptive analysis. The results suggested that majority of construction SME owners have an attitude of being profit oriented and do not concentrate on the growth of their firms. Also, negatively characterized owner attitudes such as anger, hatred, cynicism, inferiority, distrust, antagonism, resentment expressed towards personnel hinder growth of a firm. Further, the low level of educational qualification of owners has established attitudes that compel them to exhibit non-standardised managerial practices which result in poor human relations among employees thereby affecting firm's growth. An additional conclusion from the study indicates that attitudes of construction firm owners composed of three components namely cognitive component, affective/emotional component, and behavioral component.

Keywords: Attitudes; construction; growth; small and medium-size; firms.'

1. Introduction

The literature on small and medium-sized firms (SMEs) has acknowledged that SMEs are widely recognized as the critical engine of economic development [1]. This characteristic feature has given rise to the dominating SMEs policy debates around the world on how to stimulate economic growth through the development of SMEs [2]. Small and medium-size firm represent about 92 percent of Ghanaian businesses and contribute about 70 percent to the nation's GDP and more than 80 percent to employment [3]. Small and medium-sized firms contribute significantly to the growth of economies. According to Mensah (2004) in Ghana, SMEs have been identified as the catalyst for the country's economic growth as they are a primary source of income and employment. Owners of small and medium construction firms are mainly classified in terms of individual, group of people or institution ownership. The growth of a business can be measured by several attributes, such as sales, employment, assets, profit, market share and productivity [5]. Further, among these indicators, the most frequently used includes sales, employment and assets growth measures. According to [6], reviewed studies of firm's growth found sales to be the most prevalent indicator, followed by employment. Sales growth was considered important because entrepreneurs themselves frequently use this indicator when making business decisions [6].

Similarly, employment growth is deemed relevant because entrepreneurs are often willing to disclose this type of information, and it is easier for them to recall. However, for growth to be attained in a firm, the role of the owner's attitude is imperative. This is because the owner's attitude must stimulate growth via their managers of the firm. The role of the owner varies from one firm to the other depending on the sector type and businesses amongst others. Owners of firms regardless of the industry it operates have some common features and similarities including desire to make profit, ambition to impact in their niche market with its products. These indicators will inevitably impact on the firms despite ownership type however some common features such as attitude seems to be evident among these firms. Attitudes of owners firms make an impact either negatively or positively towards the growth of the business. It is against this backdrop that this study sought to explore into attitudes of owners of small and medium size construction firms (SMEs) that impede growth.

2. Purpose of the study

The purpose of this study is to establish a deeper understanding on how attitudes of firm owners' hinder on firm's growth and other related attributes of the company.

3. Methodology

In order to achieve the purpose of the study, the used of interviews supported by a review of the literature was adopted. Because of the sensitivity of the and nature of the studies on owner's attitudes of firms, selected stakeholders of the company were involved in the interview process which was held among sampled construction SMEs owners that operate within the capital city of Accra, Ghana. The selection of stakeholders facilitated the non-probability snowball sampling technique. Stakeholders of the selected construction SME firms such as suppliers, employees, client's representation, civil society group among others were used as a medium to establish vital information regarding the attitudes of owners toward growth. The interview which was informal in nature was however recorded and transcribed. The technique proved affirmative since it was quite difficult using other techniques to retrieve information on owner's attitudes. The methodology was supported by a review of existing literature on owner's attitudes towards growth. This was desk-top in nature with the particular use of journal publications, books, Government gazettes and the used of the internet for electronic information.

4. Literature Review

According to [7], various studies have emphasized on characteristic attitudes of owners of small to medium-sized business such as risk-taking and openness to change. Further, owner's attitudes towards personal, finance and risk have as well been acknowledged in the literature. The term 'attitude' refers to an individual's mental state which is on beliefs or value system, emotions, and the tendency to act in a way [8]. Owner attitudes characterized as negative towards personnel that hinder growth of a firm includes anger, hatred, cynicism, inferiority, distrust, antagonism, resentment. Employee performance is skewed anytime when such adverse owner attitude is exhibited towards them. This usually brings down moral and also goes further to affect the entire employee's output within the firm. In addition, the sense of belongingness is reduced and with individual employees ego diminished thereby attributing to desire to grow. Other aggregated owner attitudes that hinder firm's growth include complacency. This is an important aspect of the firm's culture which gives a reflection of the owners need, desires and personality. This is experienced when a firm owner is satisfied with the current status-quo of the firm and does not require any further growth [6]. Lack of risk-taking attitude of firm's owner would result in a dearth of investment. In addition, when firm owner requires leadership attitudes such as vision, courage, fortitude and the zeal to inspire staff it will have a detrimental effect on the productivity of the entire firm thereby impacting on growth.

Literature further acknowledged that owner's attitudes can be assigned to one of the three broad categories including stagnant satisfiers, thwarted expanders and capricious owners [8]. Similarly, attitude could also be composed of three components including cognitive component, affective/emotional component, and behavioral component. The cognitive component is based on the information or knowledge, whereas affective component is based on the feelings. Whiles lastly the behavioral component reflects how the attitude affects the way owners act or behave act [9].

4.1. *Stagnant owners*

These categories of dominate among firm owners. They are those whose businesses have been built to a level they regard as suiting their economic and social needs. Further, this category of owner's priorities to maintain their current level of growth rather than pursuing further growth of their firms.

4.2. *Thwarted firm owners*

Thwarted firm owners are characterized by trying to grow their business but unable to grow. This maybe as a result of labour skills shortage, low wages, salaries amongst others.

4.3. *Capricious owners*

These are a category of owners who move regularly and repeatedly into and out of an industry so as to maximize short-term gain avoid long-term liability.

5. Findings and Discussion

In order to be guided by the primary purpose of the research, informal interviews via snowball were conducted in order to establish the negative attitudes of true owners that hinder growth. It was found that various human attitudes are exhibited by firm owners that operate within the construction industry. This is because the construction industry in characterized as a labour intensive sector with accumulated different attitudes and backgrounds such as educational, political, religious amongst others of employees which must be managed by the owner. Some firm owner's remarked that the uniqueness of the construction industry in terms of its high risk has cultivated a form of attitude that deters them from embarking on growth projects for their firm. Also retrieved from the interview include inconsiderate inter-personal attitudes exhibited by owners of construction firms on employees. These consist of low human relation, lack of motivators and fundamental physiological needs of employees. Further, few interviewees retreaited that labour force plays a vital role in the construction process therefore good performance and improvement in construction productivity are achieved through prudent resource management, human efficiency, and human relations. Consequently, if firm owners do not endeavor to establish right attitude on employee relations, then productivity will undoubtedly be hindered affecting the growth of the organization. Interviewees also added that owner's attitude of fear of change as a result of uncertain turbulent political atmosphere prevents the firm from embarking on innovation to improve on products due to the volatility of the market environment. Similarly, interviewees also remarked that the fear change as a result of the unstable price quotations from suppliers due to uncertain economic stability that impedes firms growth. Respondents also asserted that most owners of the construction have a low level of education and are also profit oriented naturally rather than seeking the growth of their firms.

6. Conclusion

The purpose of the study was to explore an in-depth understanding on how attitudes of firm owners' and other related attributes of the company hinder on firm's growth.

In order to achieve the purpose of the study, the used of interviews supported by a review of existing literature was adopted. The sensitivity of the study warranted the use snowball sampling technique to be adopted for the study. Selected stakeholder's of several of construction firms were considered in the interview process which was held among owners that operate within the capital city of Accra, Ghana. The selection of stakeholders of the firms such as suppliers amongst others facilitated the non-probability snowball process. Review of this study has shown that the various studies have emphasized on characteristic attitudes of owners of small to medium-sized business such as risk-taking [7]. Further, literature also stressed that the term 'attitude' refers to an individual's mental state which is on beliefs or value system, emotions, and the tendency to act in a way [8].

The study also concludes that owner attitudes characterized as negative towards personnel that hinder growth of a firm includes anger, hatred, cynicism, inferiority, distrust, antagonism, resentment. Employee performance is skewed anytime when such adverse owner attitude is exhibited towards them. Further wrapping-up of the study indicates that owner attitude is composed of three components including cognitive component, affective/emotional component, and behavioral component. The cognitive component is based on the information or knowledge, whereas affective component is based on the feelings of the individual. An additional conclusion from the study shows that construction SME firm's owners develop an attitude that hinders growth and these emanate from the uncertain political atmosphere that results in fear for them to embark on any growth project in the firm and also supported by the fear of the unstable economic stability.

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Determinants Predicting Credit Accessibity within Small and Medium-Sized Enterprises in the South African Construction Industry

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Abstract

The contribution of Small and Medium-sized Enterprise (SME) sector in economic development, job creation and income generation has been recognized worldwide. These contributions are effectively articulated in South Africa construction industry discourse. However, the main problem limiting the SMEs sector to contribute fully in the mainstream economy is the shortage of finance. This study examines the impact of firm characteristics in access to credit by the South African SMEs in the construction industry. A deductive methodological approach was used to examine this problem. This paper utilises a combination of primary data emanating from structured survey questionnaires supplemented by secondary source of data from an extensive literature review, in order to present insightful commentary about credit accessibility within SMEs in South Africa. The structured survey questionnaire was administered to 179 construction small and medium organizations to elicit relevant data about their credit accessibility. Binary logistic regression was applied to determine the influence of demographic variables on credit accessibility. The equation specified access to credit as dependent variable while firm and personnel characteristics as independent variable. The statistical package for social science version 22 was used. The results indicate that firm characteristics influence access to finance. The study recommends that South Africa SME contractors should maintain attractive firm attributes to stimulate lenders to extend finance to their investments.

Keywords: accessibility, characteristics, construction, credit, firm, small and medium.

1. Introduction

The Small and Medium-sized Enterprise (SME) sector performs a significant roles worldwide [2]. SMEs have a potential contribution socially and economically by contributing noticeably in job creation, revenue creation, innovations, as well as a catalyst for urban and rural area's growth [20]; Organisation for Economic Co-operation Development [33]; [41], [14]. Most of the industrialized countries, over 96% of all construction and manufacturing sector firms originate from the SMEs sector and they are main employment providers [35]. The SME sector employs more than 19% of the productive labour force in the developing countries [22].In South Africa, the government has been attracted by SMEs to solve unemployment problem which recently is spreading across the country. More than 700,000 job seekers enter the South Africa labour market annually but only 44,000 new jobs are created annually within formal sector, therefore those who unable to find jobs in the formal sector end up in the informal sector whereby SMEs dominate. Despite of construction SMEs contributions in the county's job creation, their continuing growth and strengthens has been compromised by the persistent limitations on their access to credit from formal-sector. The finance gap exists in the South Africa construction SMEs sector deteriorate construction SMEs' productivity, performance and contributions to the country's economy. South African government recognizing the importance of SMEs in economic development has set up various *programs* aimed at developing the SME sector. The National Strategy for sustainable Development, [25] as a medium plan towards the reduction of poverty in the country by the year 2020. However, these strategies and programs still unattainable, SME sector still vulnerable and very few manage to survive due to shortage of credit accessibility.

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According to [34] observed that accessibility to external finance is essential to solve shortage of SMEs cash flows. Financing is required for construction SMEs' to set up and enlarge their business operations, new product development, research and development, human resource development and acquirement of up-to-date production equipment's and technology. Most of construction SMEs rely on *internal finance* since they can't afford external finance easily only prioritized source become internal finance but still internal finance is inadequate for SMEs' development and profitability. Most construction SMEs failures to access debt financing result into an inadequate capital structure. According to [12] cited that the main source of external financing for SMEs is equity and debt.[38]observed that external equity from stock exchange (capital markets) usually never exists for construction SMEs.[27]and [39] evidenced that firm characteristics have an impact on capital structure and performance of SMEs Finance gap still exists between the supply capabilities of financing sources and the demanding needs for capital to SMEs. This study intends to create a bridge to impact accessibility of credits to construction SMEs in South African.

2. Research Objective

The SME sector in South Africa is one of engine of economic growth also in many economies in developing and developed countries as it plays a major role in job creation, competition, economic enthusiasm, and innovation. The objective of the paper is to investigate the determinants predicting credit accessibility within small and medium-sized enterprises in the South African construction industry.

3. Literature Review

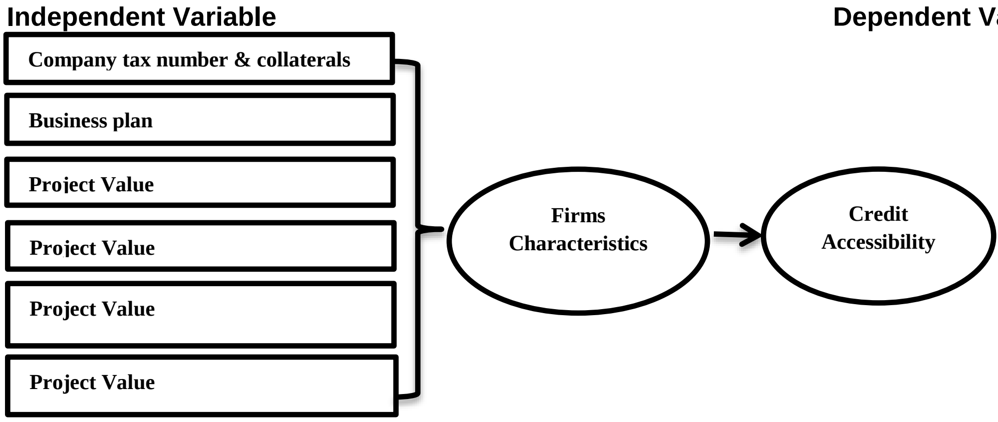
3.1. *Theoretical Framework*

The capital structure is described as the mix of debt and equity that a firm uses to finance its operations [17]; [6]. The original hypothesis of capital structure originated from the Modigliani-Miller theorem (MM theory), the study argued that the value of the firm is irrelevant in financing decisions in a perfect market [29] and [30]. The theory lacks applicability in the real world since the firm's value is relevant in financing decisions because of agency costs, bankruptcy costs, information asymmetry and tax components that impact firm's capital structure. The benefit to employ debt in a firm's capital structure exists as the interest on debt is tax-deductible, thus creating tax savings for the borrower [30]. Therefore, it is possible to reduce firm's costs of capital and maximize shareholders' wealth by employing debt. Tax saving makes debt finance cheaper than equity finance whenever employed in a firm's capital structure. The combination of inexpensive debt with relatively expensive capital equity decreases a firm's cost of capital, which is the hurdle rate for investment acceptance or rejection decisions. For a project to be pursued must be viable to generate enough cash flows to cover the initial cost of that investment. MM theory stipulated that a firm should have 100% debt in its capital structure in order for a firm to enjoy the tax shield benefit [30]. [37]and[24]point out that theoretically 100% tax shield does not exist because of the existence of financial distress costs.[40]stipulated that presence of agency problems such as asymmetric information and moral hazards can impact the access to credit and thereby capital structure of SMEs. The pecking order theory states that the presence of asymmetries of information among the stakeholders; most firms utilize in optimal internal sources available to finance their investments before opting to use debt and equity [1],[31]&[27],[31]. Despite of financial distress problem exists when firm imply debt financing in their capital structure; SMEs imply debt as the only choice available because of insufficiency of internal sources and unavailability of equity finance [15].

3.2. *SMEs Perspectives in Debt Financing*

Obstacles exist on access of external credit for SMEs led the sector to experience investment fund hence impact sector's growth [11]. Financing from internal or external source are required to stimulate firm's profitability which is the accelerator of the any business expansion and stability[32].[31]in pecking order theory states that during financing decision firms should prioritize internal sources of credit to external sources of credit in reference to availability of the source and cost involved. The internal sources of credit option are not preferred choice to be selected in credit profitable and viable projects by most firms because it is insufficient. The external credit is the only source to rescue the construction SMEs in South Africa. The borrowed fund can be invested in profitable projects to generate additional assets that can be used as collateral in the future when firm is in need of external debt credit.

Refer figure 1 which represents diagrammatically how the credit accessibility to credit firms characteristic.



3.3. *Empirical Review: Firm Characteristics*

This part presents the empirical review of the firm characteristics to be used in this study. It introduces the variable, frameworks arising from the literature and discusses how it impacts debt financing by SMEs. It constructs relevant hypotheses to be tested in the study and other immediate literature of relevance to the study.

3.3.1. Location of the Firm

According to [4] find out that the geographic closeness between lenders and customers has an association with a firm to access to credit. The lenders who are geographically proximity to their customers are capable to utilize soft available qualitative information to establish the credibility of their customers for credit quality. [17] spotted that the location of the firm has a noticeable relationship with access to the marketplace, supplies and to other resources such as capital, labour, and land. Consequently, firms sited in urban locations may have a higher possibility of success than firms located in rural locations with access to credit, market and other resources. [14] find out that SMEs located in urban are successful in access to debt financing compared those located in rural areas. Physical closeness between lenders and borrowers produce an improved form of environmental scrutinize that aid SMEs to access credit from lenders. Consequently, there is a positive relationship between firm's location and access to debt financing by SMEs.

3.3.2. Owners Equity

The industry in which a firm operates does not influence the firm's capital structure directly but might do so indirectly through the composition and nature of the firm's assets [19]. The association that exists between industrial classification and employment of debt in the capital structure originated from a theory which stated that industry classification is a substitute for business risk [3]. The concept lay in this theory indicate the firms operating in the same business sector, the environment and economic features tend to suffer the same impact face the sector which might influence earnings and growth. [19] advocated that even though particular firm features are sensitive to structural features of industry still financial strategy variables posse very important influence over industrial specific effects on the firm's operations.[1]evidenced that SMEs operate in the agricultural industry has strongest capital structure and asset structure whereby wholesale and retail industry demonstrated the weakest asset structure as well as debt ratio. Consequently, it is hypothetically exists a positive impact between the firm's industry and access to debt financing by SMEs.

3.3.3. Firm's Business plan

This study evaluates why lenders (banks and other lending agencies) are interested with firm's business information.[23]point out that lenders use firm's business information to assess current and future performance of the firm. Lenders are interested to know the status of their loan interest and principal by evaluating the firm's capital structure. Furthermore, lenders use the business information to decide borrower's credibility whether to issue or extend a loan or not. Absence of sufficient information leads to information asymmetry and may jeopardize access to credit finance [36]. Consequently, it is the hypothetical existence of a positive association between business information and access to debt financing SMEs.

3.3.4. Firm's Collaterals

SME sector faces difficulties to access external credit for their investment projects because of lack of assets to be pledged as collateral. In that perspective SMEs fail to grow due to lack of collateral to pledge to access external sources of credit. [9] pointed out that the requirement of collateral is a crucial aspect for construction SMEs to succeed in credit accessibility of external financing from lenders.[9]and [7];[13] suggested that the collateral is the lender's protection in case default happened by a borrower, in that perspective collateral is the insurance that lender's contract will be honoured and respected. Collateral solves the information asymmetry problems in the evaluation of investment project, the worthiness of the project and risk that might be involved by a borrower as well as the cost related to supervision of borrower's characters.[3]and[14]suggested that operators of construction enterprises have to own more tangible assets that can create higher value on their firm to accelerate borrowing security. Because, the higher the value of assets the lower the interest rates of the debt to be secured by those assets. Consequently, it is hypothetical existence of a strong positive relationship between collateral and access of debt financing by construction enterprises (SMEs).

3.3.5. Project Value

The firm accepts to invest only in riskier projects which can produce higher income levels, which are needed to cover debts. The result is that the lender cannot avoid selecting the riskier project and therefore must accept the risk of the firm. In the presence of excess demand, the lender has different maxima corresponding to the rates with the lower adverse selection likelihood for credit rationing [40]. Furthermore, rationing conditions reduce access to financial resources not only for new investment, but also for employment creation and poverty alleviation. Another facet of credit rationing is that financial institutions personnel/ managers may have to bear personal responsibilities for nonperforming loans if the loans are given to SMEs without government guarantees, hence agency problems exist. Managers have the responsibility to protect the depositors' interest hence will operate under credit rationing conditions.

3.3.6. Firm Tax Number

According to [29] hypothesis under corporate taxes highlighted the important issues involved in financial structure decisions namely: the cheaper cost of debt compared to equity; the increase in risk and in the cost of equity as debt increases; and the benefit of the tax deductibility of debt. They argued that in the absence of taxes, the cost of capital remained constant as the benefits of using cheaper debt were exactly offset by increase in the cost of equity due to increased risk. With taxes and deductibility of interest charges they concluded that firms should use as much debt as possible.[31]described the compromise "static trade-off" theory which firms would use a good deal of debt to take advantage of tax deductibility but not too much to avoid the increasing likelihood of costly bankruptcy. SMEs can therefore acquire credit from financial institution to meet their recurrent expenditure against their future profits

4. Research Methodology

The questionnaire was tested as our research instrument through a pilot study covering 30 construction SMEs firms. The purpose of the pilot study was not only to identify the common problems within the designed questionnaire but also to incorporate the respondent's comments that enhanced the quality of the questionnaire that met the purpose of study.This study examines the determinants predicting credit accessibility by SMEs in the South African construction industry. A deductive methodological approach was used to examine this problem. This paper utilises a combination of primary data emanating from structured survey questionnaires supplemented by secondary source of data from an extensive literature review, in order to present insightful commentary about credit accessibility within SMEs in South Africa. The structured survey questionnaire was administered to 179 construction small and medium organizations to elicit relevant data about their credit accessibility. Binary logistic regression was applied to determine the influence of demographic variables on credit accessibility. The equation specified access to credit as dependent variable while firm and personnel characteristics as independent variable. The statistical package for social science version 22 was used. The results indicate that firm characteristics predicting access to credit. The study recommends that South Africa SME contractors should maintain attractive firm attributes to stimulate lenders to extend credit to their investments.

5. Results and discussions

Out of 200 respondents, 176 (91.2%) have applied for credit from commercial banks. The results indicate that apart from owners' funds, commercial banks are the next major potential source of funds for construction SMEs. The results are consistent with [41]and [39]on the capital structure decisions of SMEs that external debt financing such as bank loans are the more common sources of funding after internal equity for many SMEs. Out of the 176 respondents that applied for credit from commercial banks, 138 respondents which is (78.4% obtain full credit from commercial bank and 38 which is 21.6% got part of credit. These results are consistent with [40] and [10] that construction SMEs are credit rationed. Binary Logistic regression was used to analyse the likelihood of obtaining full or part of the credit based on the independed variables such as cash flow statement, owner equity, firm tax number, business plan, project value, collateral, location of the firm variables on the approval of credit. According to[16] when reporting the results of a Binary logistic regression analysis, the estimated odd ratios for the regression coefficients, their confidence intervals and associated P-values should be presented. In addition, it is necessary to give some information about the goodness of fit of the model to the data as measured by the Hosmer and Lemeshow test. The Omnibus test of model coefficients is highly significant with a P-value of 0.000.The chi-square value for Hosmer-Limeshow test is 10.970 with a significance level of 0.203. The model currently predicts 79.9% of cases

Table 4: Binary Logistic Regression for Determinants Predicting Credit Accessibility for Construction SMEs

Variable	Odd ratio	Confidence interval (95%)	P-Value
Tax Number	7.724	1.083	0.041
Business Plan	0.201	0.062	0.008
Projects Value	1.000	1.000	0.013
Collateral	1.182	0.575	0.650
Location of the Business	1.145	0.846	0.380
Owners' Equity	0.879	0.577	0.548
Cash Flow Statement	0.832	0.513	0.456

The odd ratio for tax number of the firm is 7.724 with a p-value of 0.041 indicating that construction SMEs with tax number are 7.724 more likely to be successful in their applications for credit accessibility compared to SMEs without tax number and collateral. The results are consistent with other empirical studies on the importance of collateral to the availability of debt finance such as [9] and [3]. The results also indicate construction SME managed by owners' equity with business pan (odd ratio 0.201, p-value 0.008) and related business experience and project value (odd ratio 1.000, p-value 0.013) are more likely to be successful in their credit accessibility applications. The p-values for construction SME owners' equity with, collateral requirement and cash statement are higher than 0.05 indicating that they are not significantly more likely to have their credit accessibility applications successful. The results are consistent with [26] and [28]. Construction SMEs that are able to produce tax number, project value, and business plan (odd ratio 7.724, p-value 0.041) are significantly more likely to be successful in their credit applications. The results for business plans produced by an accountant are not significant. The results are consistent with the findings of [34] and [23]. With no previous relationship as the reference category, the results indicate that SMEs owners that have previously relationships and the location of the business with a bank are significantly more likely to be successful in their credit applications. However, collateral does not have any significant impact on the success of credit applications. The results are consistent with [38] and [21]

6. Summary of Findings and Discussion

The results indicate that company tax number and collateral, managerial competency (especially high education and related experience), business plan, and the project value, relationships with banks and the location of the business are important determinants predicting credit accessibility to bank credit by construction SMEs. In addition, incorporation and the size of the firm are also significant factors. In the light of these findings, the study recommends that to get debt funding from banks, it is necessary for the owner of a construction firm to have either business or personal assets to be used as collateral. Therefore, to get the required funding from commercial banks, it is first about the owner of the SME getting investment ready. Investors look out for very specific things when they assess requests for funding. Entrepreneurs must be made aware of the needs and concerns of particular types of investor. In addition, government and its agencies have, over the years, expended significant resources creating and implementing market interventions. It is vital that these interventions are effective and meet the needs of those they declare to support. It is therefore incumbent on Government and other stakeholders to ensure that these schemes, such as the Small Firm Loan Guarantee, are well publicised and available to construction enterprises.

7. Conclusion and Recommendations

The study focused only on bank credit. The determinants of other sources of credit to construction SMEs such as trade credit and government were not investigated. In addition, the study focused on the demand side. Further study could investigate the determinants of credit approval from the supply side (i.e. banks)

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Drivers for and Obstacles to Enterprise Risk Management in Construction Firms: A Literature Review

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Abstract

Regardless of the increased number of studies on Risk Management (RM) in several industries, limited studies have strived to reveal the components are driving and obstructing ERM implementation in construction firms. These firms are constantly exposed to business risks, thus requiring not only project risk management (PRM) but also a more integrated, comprehensive focused risk management approach to managing risks on an enterprise basis defined as enterprise risk management (ERM). Therefore, this study aims to identity the drivers and obstacles to ERM implementation. The work methodology included a comprehensive literature search relating to ERM. The review spanned a decade and lustrum between January 2000 and December 2015 and was based on a combination keyword search in three databases namely; Science Direct, Taylor and Francis Online, and Emerald and in Google. Thirty-one quantitative and mixed methods research were justified to be relevant in this study. The study revealed that empirical studies have identified various important drivers for ERM implementation namely; legal and regulatory compliance requirements, non-mandatory reports, credits rating agencies' requirements, reduced earnings volatility, reduced cost and losses, increased profitability and earnings. The study further revealed that lack of support from top management, management priorities, reluctance to discuss sensitive information, difficulties in quantifying the risks, lack of common risk language, lack of quality data and limited access to data were key obstacles to ERM. The identification of the obstacles enables the management to be clear about the challenges encountered by the ERM program and take corrective actions to reduce their undesirable effect. Furthermore, construction firms can use the drivers and obstacles revealed in this treatise to prepare their customized list of drivers and obstacles. The findings of this study contribute to global knowledge relating to ERM and allow the management to overcome the challenges posed by the significant obstacles.

Keyword: Construction Firms, Drivers, Entreprise Risk Management (ERM), Obstacles.

1. Introduction

In recent years, changes in the business landscape have occurred in the way firms perceive risk management (RM), and the trend has moved toward a more integrated, comprehensive RM discipline, defined as ERM [1], [2]. The Committee of Sponsoring Organisations of the Treadway Commission (COSO) [3] attached a definition to ERM as "a process, effected by an entity's board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives". The definition is adopted in this study as it applies to various industries, including the construction industry (CI). Also, it reflects that ERM should be implemented at all levels across an enterprise and applied in strategy setting to assure the achievement of corporate objectives.

ERM allows firms to shift the focus of the RM function from primarily defensive to increasingly offensive and strategic [4] and offers a new approach to enhance project risk management (PRM) in the CI [5]. Therefore, ERM has been advocated in the CI and construction firms have been seen as prime candidates for ERM adoption [6], [7].

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However, various factors influence the successful implementation of ERM. Some of them drive ERM implementation while others act as obstacles. Regardless of the increased number of studies on Enterprise Risk Management (ERM) in several industries, limited studies have strived to reveal the components are driving and obstructing ERM implementation in construction firms. Faced by these obstacles, firms in many industries tend to find it hard to implement fully ERM and the percentage of firms adopting or implementing ERM is often low [8]. In a study conducted by Beasley et al. [9], it was found that 46 percent of the global respondents had a formal ERM process while only 11 percent of American respondents possessed a complete ERM process. Similarly, Zhao et al. [10] studies showed that none of the Chinese construction firms had high-level ERM implementation, hence making it essential to investigate the obstacles confronted by these firms. Therefore, this study aims to identity via a desktop literature review drivers and obstacles to ERM implementation. An understanding of the drivers for ERM implementation enables the management to acquire necessary support for the ERM program and reinforce the positive influence of the drivers. The identification of the obstacles enables the management to be clear about the challenges encountered by the ERM program and take corrective actions to reduce their undesirable effect and overwhelm them. Furthermore, the drivers and obstacles revealed in this treatise can be used as a base for future research relating to ERM in construction firms. Hence, this study significantly contributes to global knowledge relating to ERM and allows the management to overcome the challenges posed by the significant obstacles.

The following discusses the drivers for ERM and obstacles affecting the adoption or implementation of ERM identified by literature. Some advocated solutions to the obstacles of ERM implementation are also suggested followed by methodological approach adopted and discussions of the findings and implications of the study. The final section concludes the study.

2. Literature Review

Some studies have reported the drivers for and obstacles affecting the adoption and implementation of ERM in several industries, including the CI. In this study, thirty-one (31) quantitative and mixed method approaches were reviewed and relevant for this particular study. The papers are tabulated in Table 1 and Table 2.

2.1. *Drivers for ERM Implementation*

ERM implementation has been, according to literature in various industries compelled by a series of legal compliance and corporate governance requirements [4], [11]. The majority of them are legal and regulatory compliance requirements, such as the Sarbanes-Oxley Act and New York Stock Exchange corporate governance rules in the USA, and the non-mandatory reports or standards that created public pressures and benchmarks for sound management practices, such as the COSO ERM framework. Embracing ERM has been considered as a good strategy to comply with these new risk-based governance requirements [12]. Furthermore, because ERM can increase firms' value, the three main rating agencies (Moody's, S&P and Fitch), have included a firm's ERM system as an element in their rating methodology in various industries [13]. Thus, credit rating agencies' requirements could drive ERM implementation.

While compliance and corporate governance requirements have driven firms to adopt ERM, firms in many industries conduct ERM for benefits [14]. An overall perspective of the literature is that ERM implementation can ameliorate firm performance [1]. Some of the benefits that can be derived from the implementation of ERM include, but are not limited to: reduce costs and losses, reduced earnings volatility, improved decision making, increased profitability and earnings, better risk reporting and communication, better resource allocation, increased management accountability; greater management consensus; competitive advantages, improved owners' satisfaction and improved control of an enterprise on its projects [15], [16], [17], [11], [18], [19], [20].

Moreover, a diversity of risks drives firms to adopt ERM as well. Liebenberg and Hoyt (2003) affirmed that the risks originating from the globalization and market drove firms to adopt ERM. At the same time, Pagach and Warr [14] studies concluded that firms with more volatile operating cash flows and riskier stock returns were more probable to adopt ERM.

Furthermore, the use of advanced information technology (IT) was perceived as a key external driver (Liebenberg and Hoyt, 2003) as ERM requires much computing power [21]. This breakthrough has enabled firms to collect improved records for certain risks, model complex risks, measure risks more accurately, and improved understanding of the interdependencies across a firm [22]. The improved accessibility of outsourcing possibilities for advanced IT modeling activities has made ERM available to firms that are in need of specialized risk related knowledge. Nevertheless, new studies evidence suggests that the implementation of ERM is slowed down by firms' perceived lack of technological tools [4].

Additionally, the external driving influences would require the board as well as senior management to request for ERM implementation. Kleffner et al. [15] studies reported that 51 percent of Canadian firms viewed the encouragement from the board as the fundamental element underlying their ERM implementation.

Simultaneously, Narvaez [19] asserted that top management should drive ERM implementation as ERM necessitates the commitment of the entire enterprise.

Table 1: Drivers for ERM-Literature review

Authors, Year	Objective	Methods
Liebenberg & Hoyt (2003)	To identify the critical determinants of ERM adoption	Questionnaire, statistical analysis
Manab et al., (2010)	To measure the extent to which specific firms have implemented ERM programs	Questionnaire
Wu & Olson (2009)	To explain the value of business scorecards as a means to monitor organisational performance with respect to ERM.	Review of literature
Beasley et al., (2008)	To examines equity market reactions to announcements of appointments of senior executive officers overseeing the ERM processes	Questionnaire, regression analysis
Pagach & Warr (2011)	To identify parameters that can explain variation in the "ERM mix" adopted by firms.	Interviews
Gordon et al., (2009)	To examine the relationship between Enterprise Risk Management (ERM) information content and firm performance	Reviewed drivers for ERM
Kleffner et al., (2003)	To determine the effect of ERM on business performance	Questionnaire
KPMG (2010)	To investigate the critical drivers for ERM implementation	Questionnaire
Liu et al., (2011)	To investigate the influence of the drivers in the key areas of activities of an ERM program.	statistical analysis
Muralidhar (2010)	To identify significant factors driven by ERM movement.	Questionnaire
Narvaez (2011)	To identify the critical drivers for enterprise risk management (ERM) implementation	Questionnaire survey
Nocco & Stulz (2006)	To determine the drivers for ERM program	Questionnaire survey
Segal (2001)	To understand the link between the ERM implementation drivers with the RM practices	Interviews
Jablonowski (2001)	To develop an ERM framework for construction firms	Review of Literature

2.2. *Obstacles to ERM Implementation*

Embracing an ERM approach brings about firm culture changes that, to ensure success, necessitates support from executive management, including the board [23], [24]. It is, therefore, the duty of the board to determine the risk appetite and develop the RM policy of the firm in guiding the firm's risk activities. Nevertheless, the board's insufficient RM knowledge and its compromising attitude [25], [24] may be a significant obstacle to ERM as it obstructs comprehensive and open risk discussions.

Another potential obstacle to ERM could be management's priorities [26], in addition to its reluctance to discuss sensitive information in different firm units [27], [15]. To deal with these obstacles, executive management should assume ownership of the ERM process by having a visible ERM champion who actively supports the process in order to ensure buy-in from lower level employees and to foster a 'positive tone' at the top regarding RM. This positive risk mentality should filter down through the firm and create a strong and positive RM culture in support of the risk management process [28], [24]. However, if employees agree the assigned RM responsibilities are deemed to impact adversely on them if issues are experienced, they would be predisposed to be less open and honest about potential weaknesses [29].

A further obstacle to EMR activities originates from the uncertainty about how ERM adds value to a firm [15]. To overcome this, robust support for RM activities, along with clearly defined and communicated expectations of the value the firm aims to derive from the ERM process, is important in establishing a strong risk culture [30], [23]

Successful RM is underpinned by an unchanging and foreseeable reporting structure, where risk responsibilities are clearly defined and assigned to suitable personnel [31]. However, modern firms with a 'flatter' firm design hold a challenge to RM, in that such structures are incompatible with the 'tight', hierarchical reporting systems required by ERM [32].

A further requirement to ERM success is that executive management must assume primary responsibility for RM in its corresponding areas [33]. Nonetheless, the complex nature of RM requires expertise that is best utilised if placed in one firm unit that is responsible for supervising the process. This will ensure continuity of RM actions, as well as consistency in application [34]. In practice, this is hard to implement as specialized knowledge, skills and experience are required for such a unit [24], as well as a more active organisational role that goes beyond traditional consultation activities, which may be contrary to the existing firm culture [24].

To be successful, ERM should be aligned to the management teams in the different units as this alignment helps in enhancing their understanding of the business functions they support [33]. Further key components for ensuring ERM success is the alignment of the RM strategy with the firm's overall business strategy, and the integration of RM into the organisational processes, as risks, are the best managed as close as possible to the source of the risk [35].

Each employee interprets and understands business risks differently, which imposes the formulation of a common risk language to ensure that risk is seen in a consistent and comparable way by all parties in the organisation [35]. The main obstacle in ERM implementation is the lack of a common risk language, which supports discussions around risks, both holistically and departmentally, and RM methods [36].

Barrese and Scordis [23], and Schrøder [24] indicated that RM concepts, applications, and capabilities must be imbedded into the firm's corporate training curriculum. The importance of training and learning is stressed by Weinstein et al. [25], who declared that firm and individual learning should support the ERM process.

Further obstacles highlighted by various authors to effective ERM implementation are:

- Difficulties in quantifying the risks, the wide span of the risk universe and managers' inability to understand simple risk tools [15], [37].
- The lack of quality data, limited access to data due to inadequate integration between systems, lack of data mapping and risk modeling tools, which some authors regard as the largest obstacles in effective ERM application [30], [38].
- The segmental approach towards different types of risks that still prevails in firms [39].

Table 2: Obstacles to ERM-literature review

Authors, Year	Objective	Methods
Merkley (2001)	To explore the implications of ERM for the management of strategic risks.	Questionnaire, descriptive statistics
Smiechewicz (2001)	To investigate the drivers for and hindrance to ERM	Review of literature
Chapman (2003)	To identify the critical success factors for effective ERM	Review of literature
Truslow (2003)	To uncover challenges and critical success factors for ERM	Qualitative approach
Barrese & Scordis (2003)	To provide Concepts and methods of ERM implementation	Review of literature
Schrøder (2006)	To address the deficit on integrated ERM practices.	Qualitative approach
Weinstein et al., (2003)	To identify drivers for and hindrances to enterprise risk management (ERM)	Review of literature
Funston (2003)	To evaluate the influence of drivers for and obstacles to ERM	Questionnaire, statistical analysis
Kleffner et al., (2003)	To determine the effect of ERM on business performance	Questionnaire, statistical analysis
Chapman (2001)	To identify what obstacles companies face in implementing ERM in Canada	Questionnaire survey
Skinner & Spira (2003)	To evaluate the impact of hindrances to ERM performance.	Questionnaire, statistical analysis
Prince (2000)	To evaluate factors hindering ERM implementation in construction firms	Questionnaire survey
DeLoach (2000)	To determine how the application of knowledge management processes can improve the implementation of ERM	Questionnaire survey
Weinstein (2002)	To analyze the potential barriers to implementing ERM at U.S. firms	Questionnaire, statistical analysis
Nielson et al., (2005)	To evaluate the relationship between drivers for and hindrances to ERM performance.	Questionnaire, descriptive statistics Chi-square analyses
Bologa (2003)	To analyze the potential benefits of ERM)	Questionnaire, statistical analysis,
Levine (2004)	To provide solutions to overcome barriers to ERM implementation	Questionnaire, statistical analysis

3. Methodology

The work methodology included a literature search. The study was conducted with reference to existing theoretical literature, published and unpublished literature. This study is mainly a literature review and looks at the literature relating to ERM. This is because ERM has attracted much worldwide attention in recent years [40]. The literature search spanning a decade and lustrum between January 2000 and December 2015 was conducted. This was based on systematic keyword combination search three databases namely; Science Direct, Taylor and Francis Online, and Emerald. The authors used advanced search for the database engines and basic search for Google. The keywords used for the data search were; "drivers for ERM" AND "obstacles to ERM". The basic search used was "drivers for and obstacles to risk management in construction firms". The search in the databases retrieved 3754 articles. However, after filtering the articles only fourteen (14) were relevant for obstacles to ERM and eleven (11) drivers for ERM and were all used in this study. Google search retrieved 4860 000 articles and reports. Six (6) relevant articles comprising of three on drivers for and three obstacles to ERM which were not duplicates with those obtained from Taylor and Francis online, Science direct and emerald search were used. The criteria for including the article or report were; the article/report should be peer-reviewed, be written in English, it should indicate the objective of the study, the method employed; report the results to the objective of this literature and a conclusion. This methodology is related to the study of Gildberg et al., [41]. To identify the drivers and obstacles to ERM in construction firms, twenty-nine articles, and two reports met the requirements. The articles and reports were read several times to obtain a sense of the content.

4. Lessons Learned from Literature Review

The study revealed the factors driving and obstructing ERM implementation in construction firms. Literature review revealed that various empirical studies have identified some important drivers for ERM implementation which include; legal and regulatory compliance requirements, non-mandatory reports, credits rating agencies' requirements, reduced earnings volatility, reduced cost and losses, increased profitability and earnings. The study further revealed various obstacles affecting the adoption of ERM implementation namely; the lack of support from top management, management priorities, reluctance to discuss sensitive information, difficulties in quantifying the risks, lack of common risk language, lack of quality data and limited access to data. Thus, an understanding of the drivers for ERM implementation allows the management to acquire adequate support for the ERM program and reinforce the positive influence of the drivers. The identification of the obstacles allows the management to be aware of the challenges encountered by the ERM program and take correctives actions to reduce their adverse effect and overwhelm them.

5. Conclusion

This study has examined literature related to ERM in construction firms. Through the comprehensive literature review, drivers for and obstacles to ERM implementation were identified. The treatise starts with the drivers for enterprise risk management implementation. Literature review identified a number a drivers for ERM namely; legal and regulatory compliance requirement, non-mandatory reports or standards, reduced earnings volatility, reduced cost and losses, improved decision making, increased profitability and earnings, competitive advantages, improved control of en enterprise over its projects, advances in IT, better resources allocation, encouragement from top management.

Literature further identified various obstacles affecting the adoption of ERM implementation that is; the lack of support from top management, management priorities, and reluctance to discuss sensitive information, difficulties in quantifying the risks, lack of common risk language, lack of quality data and limited access to data, insufficient resources, lack of perceived value or benefits, lack of qualified personnel to implement ERM, inadequate training on ERM, lack of the board or senior management leadership, lack of internal knowledge, skills and expertise.

Regardless of the achievement of the study objectives, there are boundaries to the conclusions. The drivers and obstacles identified in this study may not be extensive or continue to hold true with the passage of time. Moreover, as the findings were investigated in the context of construction firms as a whole, there may be geographical boundaries on the identification of the critical drivers for and obstacles to ERM implementation.

Nonetheless, the implication of this study is not restricted to construction firms because other firms can use the drivers and obstacles identified in this study to prepare their customized list of drivers and obstacles. In the meantime, the findings of this study can be used as a base for future research on ERM in the CI. Therefore, this study contributes to global knowledge relating to ERM and allows the management to overcome the challenges posed by the significant obstacles.

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Examination of Job-site Layout Approaches and Their Impact on Construction Job-site Productivity

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Abstract

In all forms of construction project delivery, job-site layout is routinely developed and designed after bid award and prior to the contractors' receipt of the notice to proceed or letter of commencement. Job-site layout decisions are made to locate temporary offices, sanitary facilities, worker rest areas, crane locations, storage and workshop areas, access points and access roads, utilities and other critical features. These jobsite design decisions affect the operational capabilities of the site and have a direct influence on both the costs and schedule through productivity. This paper will examine the various approaches utilized in practice and proposed through research for jobsite layout design and site optimization. Factors and variables considered in the identified approaches are discussed and evaluated with respect to the impact on jobsite productivity and successful contract delivery. Important factors for job-site layout are further explored through a survey of working professionals within the United Arab Emirates (UAE). Survey results are summarized, examined and discussed in relation to the variables and critical parameters identified and their effect on job-site performance and contract success. The paper concludes with a discussion of future directions for job-site benefits.

Keywords: construction; jobsite; operations; productivity

1. Introduction

Construction is a unique project-oriented manufacturing industry where prototype facilities are delivered by general contractors according to owners' requirements. These requirements are articulated in the plans, specifications and other contract documents produced by design professionals, which form the basis for bidding and tendering. Project delivery commences after the tendering process is complete and the successful general contractor is charged with construction delivery at the prescribed quality within the contractual time and cost constraints. Delivery of the project must be undertaken within unpredictable environmental conditions while managing the incorporation and delivery of a wide diversity of materials and equipment and significant capital expenditures. Efforts are further compounded by diverse involvement and interests of stakeholders, which further complicates successful project delivery in the industry.

With significant risks and complexity, the industry has developed and instantiated well-defined processes and procedures to guide the process of construction project delivery for mutual benefit of all parties involved. The industry is truly driven by the well-known motto that 'failure is not an option,' and success stories abound throughout the world. Today, the construction industry has pressed through the challenges and complexities to become one of the most satisfying and rewarding environments for engineering practice and an essential metric for gauging economic vitality.

While the construction industry has and continues to be successful in the physical facilities to support societies, it has faltered when considering total and partial (i.e. labor or equipment) productivities. The construction industry, unlike all other comparable economic sectors, has stagnant or even negative productivity growth over the last

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several decades. This means that less output is being realized for every unit of input. Owners are getting less for their money even while technologic increases and material advances transform the industry. Contractor profit margins decrease, engineers experience less design opportunity, construction disputes increase, labor rates are pressured, and bankruptcies may result. The industry has a productivity problem and positive change is required to make a difference.

When examining productivity, there are numerous avenues that can be pursued and numerous parties that can be focused upon. This includes the owner's selection of project delivery systems, designer implementation of BIM tools to minimize errors and omissions, and regulators incentivizing innovation in project delivery. Contractors can ensure that their productivities are realized and profitability ensured through proactive site-planning, implementation of lean construction principles, and innumerable other areas of consideration which influence the on-site project delivery.

The purpose of this study is to focus on elements which are under direct control of the general contractor. The research performed by Naoum in the United Kingdom [1] identified well over 100 research journal articles covering construction labor productivity. Through this work, a survey of practitioners evaluated 46 factors covering "preconstruction, activities during construction, management-related factors, organization factors and motivational and social factors," which directly impact construction labor productivity. This included process flow variables, such as overcrowding on the site, ineffective site planning and inefficient site layouts, which are the focus of this examination.

Job-site layout and site layout planning is imperative and impacts almost all operations required to deliver the facility. The site layout design process must take into account the number of temporary facilities needed for construction, the size and shape of the site as well as the construction program [2]. Temporary facilities may include but are not limited to: temporary offices, sanitary facilities, crane locations, storage areas for materials and equipment, workshops, access roads, rest areas, safety and health facilities, and security features. When decisions are made regarding the site layout, they can be difficult or costly to change as the project progresses; therefore, developing an effective site layout plan is paramount for efficient construction and ensuring productivity. With a good and efficient job-site layout excess movement of material within the site is reduced, labor productivity increased, costs and durations reduced, worker safety improved and construction quality positively impacted.

There are various approaches can be employed to develop the job-site layout design and to enhance site optimization. Each approach has to take into consideration factors and variables that will lead to job site productivity as well as successful contract delivery. This paper provides a survey of approaches identified through the literature and explores important factors for job site layout design. The importance of the factors identified were further explored through a survey implemented in the United Arab Emirates (UAE) among working professionals. Survey results are contrasted with tasks and priorities identified in the literature where possible.

2. Laying out the job-site: Approaches for design of the site

Job-site layout, as discussed in the introduction, is paramount for construction project success. The site layout must effectively address many concurrent considerations, including:

- Space provided to function on the job site and constraints on space utilizations, such as set-backs.
- Access to the job site for vehicles and as access to work areas within the job site
- Temporary facilities required including temporary offices, storage facilities, sanitary facilities and utilities
- Material handling and movement and associated worker and public safety/security measures.

There are many techniques available for utilization in job site layout development and a literature review was performed to identify current state-of-the-art and state-of-the-practice. A wide diversity of practices were identified including heuristic, rule-of-thumb approaches, optimization, and artificial-intelligence approaches. A detailed overview of research performed in this area previously has been summarized by Sadeghpour and Andayesh [3], whom surveyed nearly 100 technical journal articles from 1987 through 2015. A wide variety of approaches were identified, including knowledge based approaches (inclusive of heuristics), mathematical programming approaches (including linear and non-linear optimization), and artificial intelligence approaches (including neural networks, genetic algorithms, ant or bee-colony and swarm approaches). The vast majority of approaches focused on static site-layout development and all approaches included productivity and spatial proximity goals and objectives.

Three different approaches were identified in terms of the site-space: predetermined, grid-system and continuous space models. Objects were assigned in the space models using either a dimensionless representation, approximate dimensions or actual dimensions. For the knowledge based, heuristic and mathematical optimization based approaches, the sites were, in general, considered as continual spaces with object dimensions most frequently based on approximate dimensions in lieu of actual dimensions. For the mathematical optimization approaches, there will be an optimal solution and all other alternatives are sub-optimal in nature. The heuristic approaches produced sub-optimal solutions by definition, which are generally acceptable for implementation in practice.

Regardless of the approaches taken, Sadeghpour and Andayesh determined that decision variables could be categorized through definitions of six alternative constructs. These include: Site space approaches, How the objects were defined (boundaries, typologies and mobility), Time considerations (static, dynamic, phased), Goals and objectives, Approaches for planning/optimization, and Technique employed (genetic algorithm, neural net, etc.) Object typology included, in general and not prioritized order, are as follows:

- Temporary Facilities
- Construction Equipment
- Materials Storage Areas
- Workplaces
- Access Roads
- Site Objects

Heuristic approaches were examined in further detail by Ray and Raju [4] including three alternative approaches to assigning positions to objects on the job-site: a rule-of-thumb approach, an ad-hoc approach and a first-come/first-serve approach. The rule-of thumb approach was based entirely on judgment whereas the ad-hoc approach was rule based and incorporated more specific design criteria to suit specific needs of activities on a particular site. The third approach identified and placed objects on site based in the order in which the objects were scheduled and is termed as the first come - first served approach. Each of three approaches have advantages and disadvantages. Using a rule-of-thumb approach, cost-effective layouts could be rapidly produced while the ad-hoc and first-come approaches were useful in overcoming immediate task-related problems. However the approaches ultimately led to confusion and/or significant inefficiencies at some point during the construction. For each, additional considerations are required to finalize the layout for implementation and the approaches should thus be expanded, refined or replaced.

Alternative approaches discussed focus on the process and less on the procedure or algorithm. One such approach identified in the literature is termed as construction site utilization planning [5]. Through this approach, design decisions are facilitated through team-based decision making process and plans finalized collectively based on consensus. Proof-of-concept was articulated based on locating temporary facilities and considering when they would be required. An alternative philosophical approach identified [6] focused on a subcontracting where job site layouts decisions were based on the operational needs of independently operating subcontractors assigned to specific task. The job site layout is developed to meet the subcontractor requirements while minimizing subcontractor conflict due to space allocation, which could decrease productivity of job sites, introduce and exasperate delays and reduced employee morale in past projects [5]. Site layout approaches which take into account health and safety factors as the layout design is developed were also identified [7].

3. Evaluating current practices: a survey of working professionals

In evaluating the different approaches for job-site layout, there were many different variables and considerations employed. This included the location of entrances, requirements for temporary facilities, occupational safety and health measures, labor employed and other factors. All of these factors effect site operations and by default affect the productivity of the job-site. To clarify and to identify which factors are pertinent for productivity, a survey was developed and implemented among the construction and civil engineering community in the United Arab Emirates. Basic demographic information was collected and respondent were asked questions to evaluate whom should be responsible for developing a job-site layout. Importance of various factors in designing a productive job-site layout were evaluated using a 5-point Likert scale. The following variables were evaluated:

- Access Points: Entrance and exit locations for vehicles and personnel
- Cranes/Lifts/Support Equipment: Tower crane locations, personnel hoists/lifts, generators and temporary power
- Storage/Workshop Areas: Material storage locations, workshop areas, tool-sheds, equipment storage areas
- Worker Support Facilities: WC and toilet facilities, worker rest areas, food and food service locations
- Site Offices: General Contractor, subcontractors, owners/consultants

The survey was distributed electronically via e-mail and social media. A total of 55 responses were obtained with relatively equal participation from owners, engineers, consultants, contractors, regulators. Results were examined to identify any counter-intuitive patterns based on the ranking using average Likert response data.

4. Survey responses: Responsibility for site-planning and layout design

The survey asked participants whom had the responsibility for job-site layout: the owner, consultant, designer, general contractor, etc. This question was important to get a feel for the perspective of the respondent with respect to the clauses and provisions employed for construction. The majority of respondents felt that the task should be performed by the general contractor (39%), the consultant (30%) or the designer (26%). When considering the respondents' profession, there was little variation between engineers and construction professionals whose results generally reflected the overall numbers. Architects, however, unanimously, felt that the job-site layout should be performed by the general contractor.

Site design responsibility was also evaluated by employer type, which indicated differences between the perspectives of those working for owners versus those working for contractor or consulting engineers or designers. The majority of those employed by contractors or subcontractors (56%) felt that general contractors were responsible for the site design while 44% felt that the responsibility lied with the consultant or designer. A similar response was identified by respondents working for consultants and designers with 53% indicating that the general contractor was responsible for the job-site layout design. Those working for project owners felt that this was the responsibility of consultants (55% of respondents). This is a logical response since consultants act as the owner 'agents' and is the owner's principal point of contact for construction.

Determination of whom actually is responsible for job-site layout requires examination of the specific contract documents employed. Many of the provision in Dubai are based on FIDIC which states that, "the employer shall give the Contractor right of access to, *and possession of*, all parts of the Site," in a timely fashion without impeding or causing delay to the contractor. FIDIC further specifies that the contractor, "shall design (to the extent specified in the Contract), execute and complete the Works in accordance with the Contract," [8] and is responsible to provide, "all things and services, whether of a temporary or permanent nature, required," for completion. Furthermore, the contractor and "shall be responsible for the adequacy, stability and safety of all site operations and of all methods of construction, [e]xcept to the extent specified in the Contract." [8] Thus, FIDIC, as with most general conditions, assigns responsibility of the site to the Contractor. This further implies conveyance of the authority to design and structure the site for effective and efficient project delivery to the general contractor, which may be considered as the default position unless overridden by supplementary conditions or contractual provisions. Survey respondents did not reflect this default position so it may be presumed that contractual forms employed in practice override or, more likely, integrate the consultant and engineer into the site layout approval process.

5. Survey responses: Importance of variables in the site-planning and design process

Regarding variables considered and their relative importance for job-site layout design, results of the surveys are summarized in Tables 1 and 2. In Table 1, rankings are summarized by profession for engineers and construction professionals and whether the respondent had previous experience designing a job-site layout. In Table 2, results are summarized by the employer. Both tables compare results to the rankings developed from all respondents. Where ranks deviate by three or more positions, the rankings are shown in bold-italicized text in shaded cells to highlight differences in preferences. In general, priorities shown are reflective of element criticality with cranes, vehicular access points and material storage areas receiving the highest rankings. Owner/consultant and subcontractor site offices receive the lowest priorities when considering overall rankings.

Considering the results by the respondent's background and profession, those whom identified as engineers, irrespective of employers or direct involvement in construction, emphasized increased importance for food/food service facilities for the workers and toolsheds. Engineers de-emphasized the location of personnel hoists and lifts. Those whom identified as construction professionals increased emphasis on both the workshop areas and the equipment storage areas. Of interest is the differing opinions of those whom have previous experience. Here, respondents with previous experience significantly increased the importance of locating generators and temporary power facilities and general contractor work site offices. The location of power and generators was deemphasized by those without experience while equipment storage areas received increased priority.

Results are summarized in Table 2 by the employer. Employees of general contractors emphasize the equipment storage areas but de-emphasize the entrances and exits for personnel. Those working for owners, on the other hand, significantly increase the importance of the entrances and exits for personnel ranking this measure nearly of equal importance to the entrances and exits for vehicles, tower cranes and material storage locations. Regulators and consultants both deemphasize the importance of material storage areas and express differing opinions on worker rest-areas. Consultants ranked this as the lowest variable while regulators significantly emphasized its importance.

Table 5: Ranking of Variables by Profession and Experience with Site Layout Design

Variables	Ranking	By Profession		Previous Experience	
	All Respondents	Engineers	Construction	Yes	No
Tower crane locations	1	1	1	1	1
The entrance and exit locations for vehicles	2	2	2	2	2
Material storage locations	3	5	2	5	3
The entrance and exit locations for personnel	4	3	6	4	4
Personnel hoists and lifts	5	***9***	5	7	5
Generators and temporary power	6	4	8	***3***	***10***
Workshop areas	7	5	***4***	9	6
WC/Toilet Facilities	8	7	8	7	8
General contractor site offices	9	7	8	***5***	11
Worker rest areas	10	12	11	11	8
Equipment storage areas	11	13	***7***	***14***	***6***
Food and food service locations	12	***9***	14	13	12
Toolsheds	12	***9***	13	10	13
Owner/consultant site offices	14	15	12	12	15
Subcontractor site offices	15	14	15	15	13

Table 6: Ranking of Variables by Employer

Variables	Ranking	Employer			
	All Respondents	G/C or Sub	Owner	Consultants / Designers	Regulators
Tower crane locations	1	2	1	1	2
The entrance and exit locations for vehicles	2	3	3	2	1
Material storage locations	3	1	4	***6***	***11***
The entrance and exit locations for personnel	4	***9***	***1***	4	3
Personnel hoists and lifts	5	4	***10***	4	6
Generators and temporary power	6	5	4	7	7
Workshop areas	7	5	6	7	8
WC/Toilet Facilities	8	9	6	10	4
General contractor site offices	9	7	12	***3***	11
Worker rest areas	10	9	6	***15***	***4***
Equipment storage areas	11	***7***	***6***	12	9
Food and food service locations	12	14	12	11	9
Toolsheds	12	12	10	12	14
Owner/consultant site offices	14	15	12	***9***	14
Subcontractor site offices	15	13	15	14	13

With the results of this survey, generalizations can be made as to the importance of various elements. The general trends and rankings are logical and make sense and where there are deviations, logical explanations can be seen. Looking at the average importance and ranking of the categories (i.e. access points, cranes/lifts/support equip, storage/workshops, worker support and offices) is a useful way to generalize the data. This is shown in Table 3. In general, the trends are consistent. Those working for G/C's and subcontractors emphasize cranes/lifts/support equipment over access points, which has the second priority. Consultants and designers place increase emphasis on office locations, which directly affect their activities. Regulators have increased emphasis on worker support variables, which demonstrate care and concern for the welfare of the workforce, which is to be expected.

Table 7: Ranks by Categories

RANKS	Table 1			Table 2			
	All Respondents	Profession: Engineers & Constructors	Experienced & Non-experienced	G/C or Sub	Owner	Consultants / Designers	Regulators
Access Points	1	1	1	2	1	1	1
Cranes/Lifts/Support Equip	2	2	2	1	2	2	2
Offices	5	5	5	5	5	3	5
Storage/Workshops	3	3	3	3	3	4	4
Worker Support	4	4	4	4	4	5	3

6. Summary and conclusion

As discussed, the construction industry has a productivity problem and there are many different areas where significant contributions can be made to impact and drive significant change. For the general contractor, one area of paramount interest is the relationship between the job-site layout and construction productivity. There are many different techniques that have been developed and explored throughout the last several decades to provide decision support to facilitate efficient and effective job-site layout design. Approaches include heuristic and knowledge-based techniques, mathematical optimization and resource assignment techniques and artificial intelligence. Techniques for managing collaborative teams to drive job-site layouts through consensus decision making have also been proposed and were discussed herein. Most approaches demonstrated proof of concept and provide consideration of various constructs at different levels of detail. This includes consideration of temporary facilities, construction equipment, storage areas, workspaces, access roads and site objects. To determine which specific elements practitioners in the UAE prioritize in terms of site layout design, a survey was developed and implemented. Results allowed specific consideration of differences in variables based on profession, whether the respondent had previous experience in site layout design, and the respondents' employer. It was seen that the most important priorities are the tower-crane location, vehicular access points, and material storage locations. The priority of worker support variables, such as rest areas, versus office locations varied based on the perspective of the respondent. Results enable re-examination of prioritization of job-site element given the variety of alternative approaches proposed.

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Knowledge Management (KM) in Concurrent Construction Projects

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Abstract

One critical factor in construction industry is how well firms manage concurrent projects effectively and obtain desired construction benefits. However, achieving this is not easy and challenging because several activities need tacit and explicit knowledge involved. The purpose of this research is to develop a generic KM algorithm using learning from and sharing to (LXS) matrix. We discussed the main concepts and strategies for rapid learning through KM in construction projects. . Some of the concepts discussed are (set-based thinking, agile PM and planning, iteration management, etc.). Moreover, the research carried out practical discussions in one of Norwegian construction project. The research looked at key literature in the field, identify the main issues in organizing KM in construction projects, and finally discuss the case of E39 ferry-free highway construction proposed by Norwegian public road authority (NPRA). The result from the KM matrix showed smaller projects are better to learn from all project phases than the large projects. The vice versa is true from sharing perspective. The research results instigate the roles of learning and sharing and urge to intervene systemic KM in concurrent construction projects.

Keywords: construction projects; knowledge management, learning, sharing, tacit and explicit knowledge.

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1. Introduction

According to PM magazines recently published on PMI, managing multiple/concurrent projects bemoaned by project managers. This is mainly because managing multiple projects overload managers with more work, affect project performance, and in some cases create challenges to complete projects with a given resources (time and budget). On the other hand, competitiveness, resource scarcity, and the need for resource optimization push industries forward to manage multiple projects concurrently. General literature considers construction industries as a competitive, with a tight schedule, diversified processes and not standardized production. In addition, several stakeholders and actors temporarily assigned to complete the projects and this even make more challenging to manage the project. These typically create pressure on construction managers to hold challenging responsibilities and handle various projects with complex activities simultaneously.

In such challenging situation, construction managers need to have capability (knowledge) on how to prioritize, execute (handle) various activities, and ability to utilize appropriate methods (tools) effectively. According to [16], project managers are special type of professionals with special knowledge, skills and training. Recent literature discussed about the need and advantages of learning and knowledge management in construction [2]. To obtain the benefits from KM, construction firms put their endeavor to expose project managers for formal training to build the knowledge and develop the PM skills. According to [5, 18], construction projects have great knowledge and information flows during lifecycle of the project which is considered an asset for companies that should not be wasted.

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The goals of these efforts are to enhance the learning and sharing process. Learning and/or sharing could be within ongoing projects, completed projects, and experienced personnel involved in these projects. In this regard, [1] argue that reuse of existing organizational knowledge, which gained through experience, can greatly reduce the time spent on problem solving and increase the quality of work. Construction projects can learn from within the same company or outsiders, and from both small/large projects of shorter/longer project life spans. The type of knowledge acquired through the learning and sharing process could be tacit or explicit [12]. Fortunately, the relevance of both tacit and explicit knowledge, the distinction between them, critical success factors and the likes are well documented in KM literature. Nevertheless, only a relatively small proportion of construction organizations have implemented KM systems [5]. Indeed, some construction organizations embedded KM as a strategy. According to [20], 40% of the construction already have the strategy but it seems took longer time to invest on it.

One challenge is how to evaluate or measure KM. Typically, lack of systematic methods of learning and sharing processes that are feasibly difficult to evaluate in practice. In this connection, there is lack of real-time and readily exploitable (usable) methods (tools). According to the general literature, KM methodological developments and the capability to use these methods would help to create value on the construction investment.

According to [21], knowledge will not bring value unless it is actively used. To use knowledge effectively in construction projects, firms should consider KM as a part of firm's strategies. Literature notably identified KM as a framework for designing an organization's strategy that can help to learn, to create economic and social value [14]. In the same light, the strategic advantages of KM has been considered as a key driver for organizational performance and competitiveness. Regardless of several discussions on strategic advantages of KM in literature, our research would focus on methodological improvement as a part of KM implementation while managing concurrent projects. Typically, this research focuses on learning/sharing the knowledge and experiences in various sized multi construction projects. We approached the discussion using the following main research questions:

- How can we systematically identify projects to ''learn or share'' knowledge to other projects with various project size and life span?
- How projects can facilitate KM in the learning and sharing process? States of the art discussions.
- What could construction project get or benefited from these processes?

2. Methodology

The paper is conceptual but in light of practical discussion from Norwegian construction project. The need for this research emanates from lack of formal methodology for learning and sharing process in knowledge based construction organizations. Typically, in construction that run several concurrent projects with different size and project life span. The research uses KM and construction focused literature. In addition, it discovers some good practices and adaptable methods from production (product development) systems, such as iteration management, set-based thinking, and agile PM planning. The paper attempted to develop learning and sharing matrix to facilitate KM in construction.

3. Knowledge management in construction and conceptual matrix development

3.1. *Knowledge Management in construction projects*

Generally, KM assumed to be existed in any organizations. Literature showed the long history of KM in various organizations and several researchers developed models that suit these organizations [12, 19]. However, [5] showed a small proportion of construction organizations have implemented KM systems. The survey by [20] indicated about 40% construction organization already have a KM strategy. Indeed, there are limited attempts to apply advanced methods of KM in construction to [13]. Although the recent publications documented an increasing trend on the awareness of KM concepts, it takes some time for the construction industry to invest on it. Nevertheless, in the 21 century with increasing demands in construction due to population growth, immigration, the need for fast economic development and the likes push construction industries to develop KM strategy, which considered as an asset in an organization.

According to [18], organizational knowledge is a valuable, rare, inimitable and non-replaceable strategic asset. This asset can be organized in a way that it creates value and make usable by the organization [21]. In the process of value creation in connection with KM in large and complex projects, knowledge transfer (sharing and rapid learning), agile PM planning, set-based thinking, proper iteration management and system integration are crucial. However, these different knowledge enhancement processes discussed separately in different cases and fields of studies in the general literature. Very limited research highlighted the system integration part. Especially the practical implications and looking a large/complex project as a system is rarely discussed.

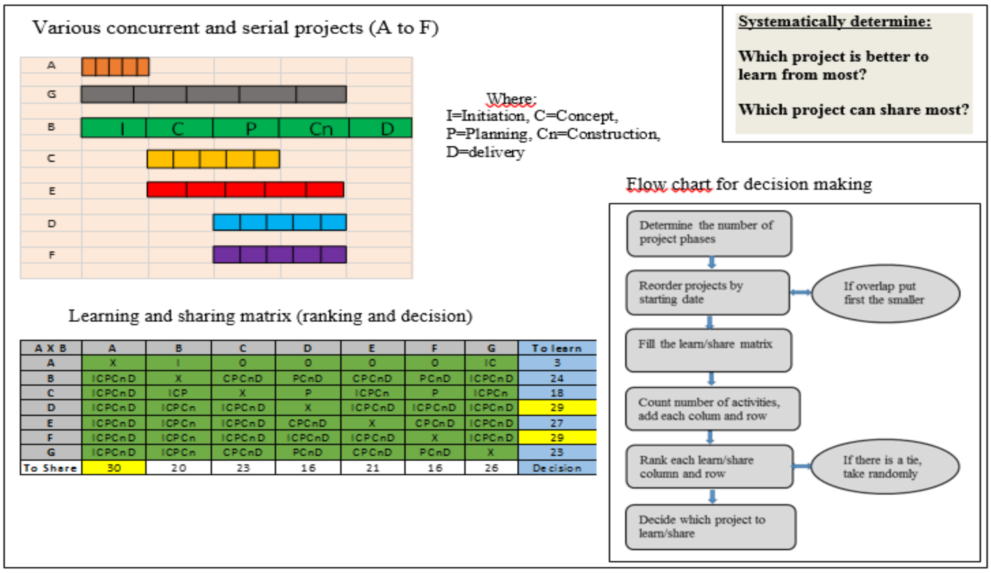
To gain competitive advantages of large or megaprojects, obtain the expected benefits & values, construction projects should have KM strategy (systemic framework) that facilitate the execution of a successful project. Typically, public construction projects aims to delight the public by exceeding their expectations and/or achieve the promised benefits in terms of various parameters (e.g. cost, time, quality, HSE).

As a contribution to achieve the aforementioned aims, we first discuss the various concepts of KM enhancing processes, such as agile PM planning, set-based thinking, iteration management, learning & sharing, and finally develop a system integration framework. In this connection, we approached by responding to the three research questions and link practical discussions to Norwegian E39 ferry-free coastal highway construction.

- ***Research Question 1*** How can we systematically identify projects to ‘‘learn from or share to’’ other projects with various project size and life span?

3.2. *Development of learning from and sharing to Matrix:*

Megaprojects lack similar previously completed projects for learning purposes. Most of megaprojects are new and need political decisions besides to the quality of the project proposal. Hence, the learning process dependent on the large and small size projects. The general KM literature showed how learning and sharing could benefit the organization performance by reducing cost, time and enhance quality. However, most these literature did not discuss about how construction managers can systematically select projects for learning and sharing. To fill this gap, we develop a hypothetical learning and sharing (LXS) matrix to select the right project with its flow-chart (see figure 1). For example, concurrent and serial projects (A to F) with five project stages (I, C, P, Cn, D) considered. Project D&F are better for learning and project A has potential to share most.



A X B	A	B	C	D	E	F	G	To learn
A	X	I	O	O	O	O	IC	3
B	ICPCnD	X	CPCnD	PCnD	CPCnD	PCnD	ICPCnD	24
C	ICPCnD	ICP	X	P	ICPCn	P	ICPCn	18
D	ICPCnD	ICPCn	ICPCnD	X	ICPCnD	ICPCnD	ICPCnD	29
E	ICPCnD	ICPCn	ICPCnD	CPCnD	X	CPCnD	ICPCnD	27
F	ICPCnD	ICPCn	ICPCnD	ICPCnD	ICPCnD	X	ICPCnD	29
G	ICPCnD	ICPCn	CPCnD	PCnD	CPCnD	PCnD	X	23
To Share	30	20	23	16	21	16	26	Decision

Fig.1 learning and sharing matrix.

Research Question 2 • How projects can facilitate the learning and sharing process? State of the art discussion

3.3. *Agile project management and planning.*

According to [3], most project managers need to follow a well-prepared plan and struggle to fight back on the plan when things go wrong. This typically force project managers to over utilize resources especially when the plan do not fulfill the rigid project requirements set at early stage. One characteristic of construction projects is scope change [16]. The more the project scope changes, the more agility required. In responding to the scope change challenges, agile project management (APM) introduced. The type of plan in APM should be realistic for the planners to respond in the short term to deliver early value, mitigate risk of the entire project [3].

Since the influence of the construction project is large at early planning phase, the cost of making changes increases with time [4] In this regard, construction firms resist (restrain) to the change from the original plan struggle to keep the original requirements as is in the beginning. However, change is proverbial as the construction project progresses because several expected and unexpected factors involved. Especially the unexpected ones force project managers to change the original plan.

In general, scope change could be due to value adding activities for expansion (modification) or because of uncontrollable (unexpected) phenomenon that require additional resources. Managing both type of changes need real-time decisions, flexibility, and optimization of resources. In this connection, literature recently showed some positive achievements of one planning framework adopted from lean production systems known as agile planning.

The emergence of agile planning is to fill the gap of the ordinary ‘‘waterfall’’ planning approach in which one cannot start the next step until the previous stage completed. In some civil engineering works which are monolithic in nature (e.g. skyscraper), iteration is rare and the waterfall approach could work pretty well. However, for non-monolithic projects, such as road constructions, iteration (agility) is inevitable. Agile planning (iteration management) is an active engagement of discussing the project goals, objectives, strategies and tasks that the project owner need to accomplish in the best way possible. Iteration is one of the distinct feature of agile planning. Typically, its relevance is feasible in large and megaprojects as these projects involve several stakeholders and factors.

3.4. *Set-based thinking (SBT) for rapid learning process.*

Although set-based thinking is one of the novel Toyota management system, it has recently been adopted to other industries. Construction is one of those industries attempting to apply SBT approach to facilitate design and project management [9]. According to [16] unlike point based (single alternative) approach, SBT is a design practice of reasoning, developing, communicating sets of solution in parallel but independently, understanding trade-offs, and finally narrowing respective sets of solutions based on additional information from other functions and customer. In line with [16], [11] claim adopting set-based practices encourages rapid learning, can eliminate rework at the root cause and the knowledge generated from SBT is often reusable for future projects.

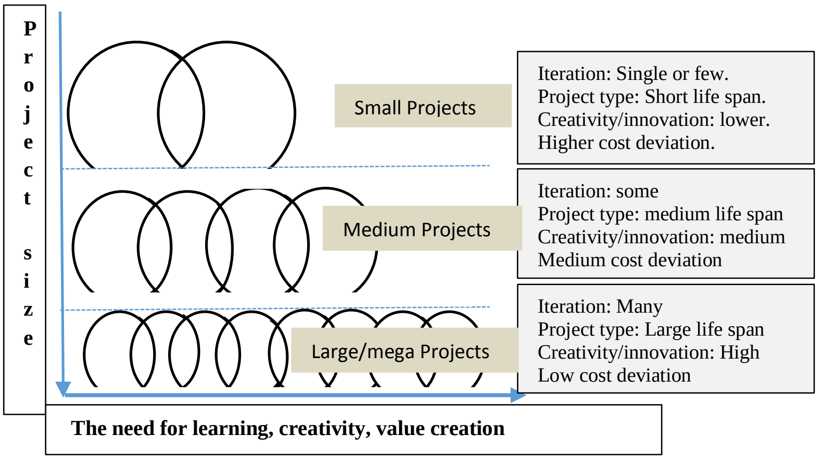
The peculiar characteristics of set based thinking is its fast learning process, event-driven solutions at different stages of the process. Set-based approach helps to converge different ideas (alternatives) into a single best solution. This process considered as a framework to enhance innovation and creativity. In this approach, the interaction between teams and different ideas are fast but the decision is late until the best idea comes out. SBT reduces the unnecessary prolonged iteration and support short cycle but fast iterations. Therefore, rapid learning plays a significant role to facilitate SBT. One important consideration in SBT is event- driven management that synchronize events as parts of a big project to solve special challenges (bottlenecks) throughout the stage gates. This literally means the process of breaking larger problems and challenges down into smaller but manageable parts that is in line with [10] proposal to handle complexity and diversification. By doing this and approaching SBT properly, it is possible to obtain four times more efficient than traditional stage-gate processes [6, 7, 8].

3.5. *Iteration management*

Development of KM strategy in construction require iterative activities as they evolve several complex activities (processes) and stakeholders. To withstand the challenges that are emanated from the complexity (diversification of activities) of the project, construction managers need good understanding on iteration management. According to [9] iteration can be seen from negative or positive perceptions. The first perception is the one that see iterations from its negative consequences. The type of iterations, which are unnecessary and do not generate value, are normally considered as a waste. On the other hand, the second perception claims the positive achievements of iterations on value creation, facilitating innovation and creativity.

Both the positive and negative effects of iteration has been discussed in construction literature but iteration management has been popular in product development. According to [10], managing several but diversified projects create complexity on management. The complexity may not because of the number of projects but also from the nature of the individual project complexities. Managing a single but complex and large project could be difficult than managing multi-projects that are small/medium sized with less complexity. Hence, the degree of requirement for iteration management and communication between teams of various discipline could vary accordingly. According to the general literature, long life span and complex projects could require iteration management more than the smaller life span with less complexity. Regardless on the levels of requirement in various sizes, complexities and life span of the project, systemic iteration management helps to acquire, analyze, store, disseminate information, and facilitate innovation and creativity in construction. Systematically managed iteration shortens the innovation cycle and can keep the construction industries competitive in the market.

Typically, having rapid, many iteration reduces risk, create opportunity for innovative (creative) ideas and finally lower the total cost of the project.



Research Question 3 What can construction projects benefited from these KM processes.

The ultimate aim of any construction of public infrastructures is to provide high standard and quality services to the public. This can achieved by fulfilling the goals of customer delight, which is exceeding the expectation of the public in this case. Therefore, it is important to make the public loyal to the construction, provide evidences that the public can be benefited (profitable) for the investment and create positive attitude about the construction.

To achieve these goals, it is important to show some explicitly measureable parameters together with intangible benefits of the construction build. Like projects in other disciplines, time, cost and quality has been used as a measure of performance in construction. However, constructing large public investment infrastructures requires and prioritize the overall satisfaction of the public. Because the investors (taxpayers) and one of the beneficiaries are the public, it important to make sure the construction project exceed the required expectation. To do this, all stakeholders should optimize resources and think beyond the specified project requirements in terms of time, cost and quality. Quality of service (i.e. technical, health, safety, environmental, etc.) should be the highest priority to satisfy the public. In this regard and for practical reasons, optimizing time, cost and quality needed for the feasibility of the project.

4. Practical discussions in light of Norwegian megaproject (E39 ferry-free coastal highway)

Norwegian public road authority (NPRA) have been responsible for several different sized construction projects. NPRA plans to construct one of the largest project (megaproject) known as E39 ferry-free coastal highway. It connects different cities and counties from Trondheim to Kristiansand. Although the expectations from E39 is huge as any megaprojects does, there are practical challenges that it should undergo, such as reducing the total travel time it took, crossing very deep fjords, topological challenges, use advanced and efficient technologies, etc. NPRA aims to reduce travel time by about half (from 21 to 12hrs.), facilitate and provide best transport services, safeguard the HSE issues.

Currently, the project is investigating various technologies and optimal solutions for the expected challenges, cost reduction strategies and implementation strategies, attempts to assess the wider impact and socio-economic benefits analysis etc. In the efforts to respond the challenges, lots of knowledge created from various stakeholders (NPRA, research institutes, etc.). There are various research groups (teams) working in different discipline with tacit and explicit knowledge. Advanced but diversified groups, teams, individuals, other internal and external stakeholders obtain this knowledge. Therefore, as the main questions discussed in section 3 and in connection with KM enhancement strategies, we will organize a systemic framework (next work) that could help E39 ferry-free fjord crossing coastal highway.

4.1. *The need for system thinking and system integration:*

Obviously, system thinking and system integration is important while planning to construct large public investment projects like E39. The issue is how project managers can wisely carry out system integration so that all the stakeholders obtain better knowledge about the project. In E39 project, several teams and stakeholders involved for the success of the project. So far, different teams, research groups and the management has carried out several research and activities. Although the current phase of the project is at fuzzy front end, where different alternative ideas and technologies assessed, diversified ideas should converge to a single best solution. This can be achieved by implementing system thinking and integration. This provides fast feedback mechanisms for different teams working in different research institution, NPRA, and other stakeholders. The next work of this research would be develop a systemic framework for system integration through KM strategies.

5. Conclusion

Most construction projects are polylithic with several iteration, repeatedly changing processes and activities. To handle the unwanted changes, implementing a systematic KM strategy is eminent. As a part of this strategy, this paper introduces a conceptual learning and sharing matrix. It helps to determine systematically which project are better for learning and sharing. For example, smaller life span project found to be better for learning and the larger ones for sharing. The paper also discussed how to approach KM through the rapid learning strategies using set-based thinking, iteration management agile PM and planning. From the practical discussion of E39 ferry free coastal highway, the research highlighted the need for system thinking and integration. The future work will be synchronizing the aforementioned concepts in the systemic way and prepare a road map for KM implementation in megaprojects.

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Evaluation of Maturity of BIM Tools across Different Software Platforms

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Abstract

The paper is dealing with the evaluation of usability and readiness of information modelling tools on the most common operating systems (Windows, Linux, Mac OS X). Stages of BIM maturity and availability of building information modelling tools vary dramatically on these platforms. Products are often presented only through the lenses of marketing departments, which emphasize positives and do not indicate any shortcomings and incompleteness of their solutions. In some cases, BIM is just an empty marketing phrase. What is missing is a general and impartial comparison tool, which rates the degree of maturity and usability of these tools in practice. Paper compares the current software tools, especially in terms of usability in the building process. The list of attributes that mature software platform should accommodate was created. Evaluation criteria are determined based on specific needs of the various participants of the building process, which leads to the successful project completion and subsequent management of the lifecycle of the building. Results can help facilitate orientation in the field of available tools/methodologies and help the adaptation of BIM in the construction market.

BIM; building information modeling; evaluation; software;

1. Introduction

Building information modeling (BIM) is clearly the future. Right now many countries across the world are in different stages of adopting BIM into their legislation. Although the idea of information modeling in civil engineering is already known for more than three decades, it is still rapidly changing and evolving. In many ways it is still in the innovation stage, but the construction and civil engineering industries generally recognize the need for BIM and the potential benefits that BIM will bring. According to Mr. Barnes and Mr. Davies, there are certain perceived barriers that may prevent organizations from fully engaging with BIM. The first barrier is already mentioned readiness of BIM. The second is perception that training costs are high, the education requirements are unknown and the learning curve is steep. The third perceived barrier is that investment in new technology, hardware and software is needed, and the potential cost of that investment is not justified by the potential savings that may be gained at this stage. [1]

This paper is partially dealing with the first and partially with the third barrier. The list of attributes that mature software platform should accommodate was developed. This was used to determine state of maturity of the platform through particular selected tools.

At this point, there is no real definition what BIM is, and what it is not. Also it is hard to predict what it can become. There are already some conventional categories called “Levels” and movement from one level of BIM usage to another is referred to as BIM maturity. [1] These levels are as follows:

- Level 0 – It is not really BIM at all. It uses only 2D CAD files for design and production information.
- Level 1 – It uses 3D data to represent design. This level is also known as lonely BIM. At this level it may be that there are a number of designers, but each is working in isolation dealing only with his own model. Some standard data structure and formats are used. Also some separate stand-alone finance and cost management packages can be used. But never integrated in the general BIM model.

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- Level 2 – At this level are BIM advantages finally more utilized. Managed 3D format is held in separate BIM discipline software tools with data attached. Another significant characteristic is utilization of COBie (Construction Operations Building Information Exchange). The formalization of this information exchange necessitates the creation of agreed principles by which data will be shared and parties will cooperate as maturity nears Level 3. It may also introduce first steps towards construction sequencing data or cost information.
- Level 3 – At this level we work with fully integrated and collaborative real-time project model. This model is likely to be facilitated by web services. It will be complaint with emerging Industry Foundation Classes (IFC)/buildingSMART Data Dictionary standards. Hurdles to software interoperability will have to be overcome, as will infrastructure and legal obstacles. At this level BIM models will utilize construction sequencing, cost information, project life-cycle and other management information, and will be driven by the development of standard libraries of object data, which will include manufactures information. [1]

There is also other way to determining BIM maturity. This approach relates to model itself and is described simply by dimensions of model. In this case we can think of 3D model as a platform onto which are built other applications that may be used through the planning, design, construction and facility operation processes. [1] This way everything that has to do something with visual model itself can be categorized as part of 3D model. That includes model walkthroughs, project visualization, clash detection, virtual mock-up models, prefabrication and other information that has to do with dimensions and space itself.

The 4th dimension (time) provides for contracture planning, schedule visualization and management. The element of time helps to better determine critical paths and visually show the dependency of some sequences on others. Now model can also include some temporary components such as cranes, lorries and others.

The 5th dimension adds money (cost) to the picture. This also fully utilizes quantity take-offs. With such an information BIM can provide not just real time cost estimating, but whole life-cycle cost.

Some literature [1,2] also mentions 6th and 7th dimension which includes facility management tools that provides improved space management, streamlined maintenance. Some experts do not see a meaning in categorizing into these "virtual" dimensions. Therefore, there is also growing trend to refer to all the extended application using 3D base platform simply as an XD.

Other important issue that has to be mentioned in context of BIM software is its impact on risk management. [3] If platform that company operates on is not stable, it can create some serious threats. That is why proper evaluation before implementation of the platform is so essential.

Main objective of this paper is with use of defined criteria determine actual state of BIM maturity on various operating systems, that are commonly used on personal computers of today.

2. BIM maturity across software platforms

First step of the research was to determine what are current market shares of operating systems amongst desktop users. This helped to determine each platforms' importance. For this step internet users' data were used. [4] Research focused on trends for the last ten years. As we can see from the graph (1), Windows platform is registering sudden steadily decline. Its overall market share went from nearly 90% in 2006 to 79% in 2016. On the other hand, Mac OS X is still on the rise. This, in the eighties almost dead platform, is now reaching 10% of the market share. Unfortunately, this showed only general statistics. To do research focused solely on civil engineers and their preferences is not in the capacity of this paper. This graph also does not reflect some specific markets. For example, in U.S. market share for Mac OS X was towards the end of the last year close to 18%. [5]

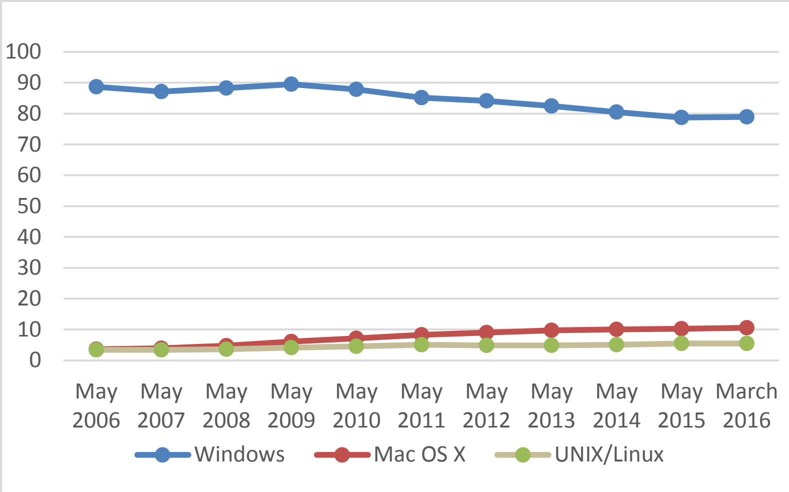

Figure 1: Graph of OS platform market share development since 2006 to 2016

The next step of the research was to define attributes of mature BIM platform. Based on generally recognized BIM levels (presented in the first chapter of the paper) and model dimensions (combined with user experience), the list of traits of mature BIM platform was created.

Mature BIM platform should provide:

- Openness, interoperability and compatibility – Software should allow wide range of data exchange. Must support import and export of IFC files and be able to support COBie. Also be able directly work with the cloud storage and offer advanced model sharing.
- Simplicity and functionality- Software should be easy to learn and understand.
- Accuracy of data – Tools should be able to give accurate information about the model. Very important are correct calculations of quantities from model.
- Expandability – Software should have option to work with 3rd party software plugins.
- Capable of advanced life-cycle and energy modeling – One of the very important requirements, since governments all over the world have pretty high goals on reducing carbon footprint. BIM tools will play crucial role in achieving that goal.
- Time management and clash detection – Tools should be able to visualize construction planning and dependencies as well as find collisions and solve collisions before the construction starts.
- Cost estimation – Software should work with the model and store data directly inside the model. It should be able to work on the fly and with respective accuracy give an overview of the expected project costs.
- Facility management – These FM systems should be able to fully utilize all the BIM data. It should help with managing day to day tasks of building maintenance as well as unexpected events.

These are in the nutshell currently known ways how to utilize building information models of today. It does not mean that people actually use all these features during the life-cycle of the building. Most projects of today are realized at BIM Level 0, 1 or 2. [6]

2.1. *BIM on Windows operating system*

Today it is the most used operating system family on the market. Therefore, it is logical that most software dealing with BIM is written for this platform. It is also benchmark for all the other platforms. We can find piece of software for all the features that were mentioned in the previous chapters. This paper does not go into details about all the functionality of mentioned software. More information about programs can be found through references.

There are three major tools for model creation. Autodesk Revit [7,8], Graphisoft ArchiCAD [9], Nemetschek Allplan [10]. There are also other design tools like Nemetschek Vectorworks [11], BricsCAD [12] and free tool Edificius [13] that are worth to mention.

As is apparent from Table 1., there is software tool for every category of listed BIM maturity level. Table is not even close to listing all of the BIM tools that exists for Windows platform. This is not the goal of the paper. Research is more focused on other two smaller platforms, in order to find out if they can compete in the terms of functionality and usability.

2.2. *BIM on Mac OS X operating system*

It is well known, that for a lot of artists and graphics designers is this a platform of choice. Some people prefer this platform over the other two because of its simplicity and user friendliness. Some programs for editing video and sound are even faster on this system than on the PC with same specification. Unfortunately, there is not as many solid software tools for architects and civil engineers. From Figure 1 is clear, that despite the fact that Mac OSX is still more and more popular, from developers' point of view it is still minor platform. Due to the fact that BIM software is highly specialized and development is fairly complex and expensive, there is not going to be any change soon. Overall on this platform dominates ArchiCAD, which was first developed for Mac and then for PC.

Despite what was said, there might be a version of Revit for Mac as well in the future. Since Autodesk revived its Autocad version for Mac in recent years.

Other types of BIM tools for this platform are unfortunately non existing. Most of those that you can use with Mac are web-based and they are not tied to certain operating system.

2.3. *BIM on Linux/Unix based operating systems*

Since Unix/Linux based operating systems are even more rare amongst civil engineers and architects, is situation with variety BIM tools even worse than on MAC OSX platform. The only tool that can be considered functional is BricsCad [12] from company called Bricsys. It would be naive to expect, that some company would invest their time and resource into developing software for platform, that has only 5% of the market share. The future of BIM on Unix based operating systems can come from community developers or universities. That is case of the B-procesor[14]. This software started as a university project developed by the Arhus School of Architecture in cooperation with the Alexandra institute. Unfortunately, it seems that since 2013 development of this software stopped. At picture below (2) there is example of typical B-processor layout. Right now you can use it to model just simple objects and shapes and assign some information attributes. This can be considered BIM, but it is far from actually useful tool. Since both BricsCAD and B-processor are written in JAVA, they are platform independent. That proves that they were not developed for the Linux platform itself, but its compatibility is given by the nature of their programing language.

There is still a segment where it might be interesting to develop BIM tools for Unix/Linux based operating systems. It is government. For example, French police and parliament migrated to Linux back in 2007. In was reported, that they saved over 50 mil. € on licensing fees between 2004 and 2008. [15] For this use of BIM you only need tools able to read BIM data. There should be no need for government clerks to be able to edit BIM data. At most they might need to revise and that is functionality that most of middleware BIM tools provide.

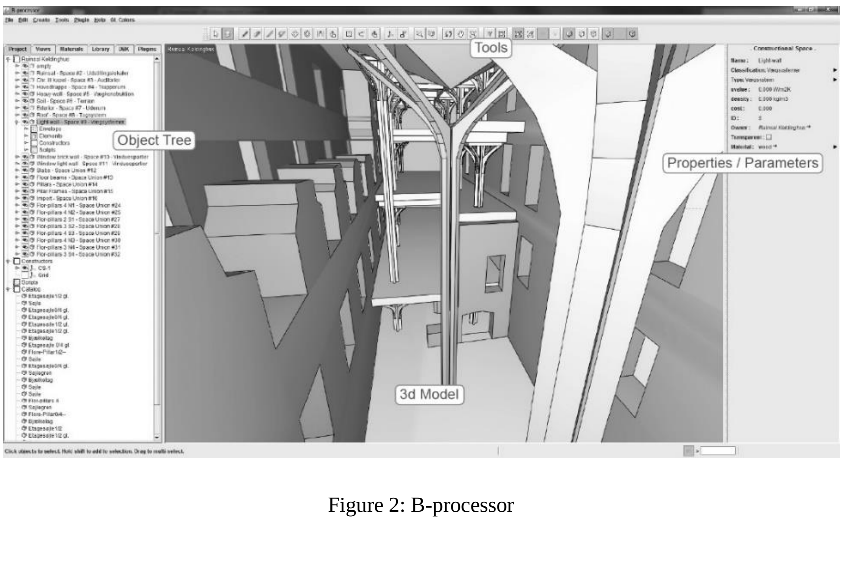

Figure 2: B-processor

Table 1. Maturity of BIM across software platforms

Types of BIM tools / Platform	Windows	Mac OS X	UNIX/Linux
BIM modeling tools	Revit ArchiCAD Vectorworks BricsCAD	ArchiCAD Vectorworks BricsCAD	BricsCAD B-processor
Clash analysis	Navisworks BIMSight Solibri Model Checker		
Structural analysis	Revit Scia Engineer		
Construction scheduling	Navisworks		
Energy analysis	Revit		
Quantity take-offs	Navisworks Sigma estimates		
Cost estimating	Sigma estimates Vico systems		
Middleware BIM Tools	Onuma 4projects BIMx BIM+	BIMx Onuma 4projects BIM+	Onuma 4projects BIM+
FM software	Autodesk Revit Allfa Archibus Archifm.net	Archifm.net	Archifm.net

3. Conclusion

This paper is focused on analyzing BIM from the perspective of operating systems. In conclusion results were as expected. BIM is still dominated by Windows platform, for which most of the software is written. Level of maturity on Windows is really high. There is still a lot of tools, that are often not fully utilized by most of the BIM adopters.

Situation on other two researched platforms is quite similar to each other. We can find few BIM design tools, but more specialized applications of BIM are missing. We also established, that Unix/Linux platform has its place at the government level. It would be beneficial for clerks to have option to use some free alternatives to payed software, since it would save money of tax payers and help accommodate BIM model as a part of procurement.

Follow-up research will be focused more closely on utilizing BIM in cost estimating. There is still a lot to accomplish at this field of research.

Acknowledgements

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Incorporating Lean Construction Agent into the Building Standards Act: The Spanish Case Study

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Abstract

There is a demand for Lean Construction in Europe; even though it is still emerging, there is a growing interest, but there are no regulations on this topic. The main objective of this research is to regulate this role when in a project, and to define and develop a Building Agent structure, according to the Building Standards Act (LOE by its acronym in Spanish), in order to be able to incorporate it into the Spanish law, protecting it from civil liabilities. In Spain there is jurisprudence in civil jurisdiction based on the LOE to acquit or convict building agents, which are defined in the courts as "constructive managers" or similar. For this reason, courts could establish in the future several liabilities between the Lean Construction Specialist and other agents of the project, depending on their actions and based on the implementation of the Lean Project Delivery System (LPDS), the Target Value Design (TVD), and the Integrated Project Delivery (IPD). On the other hand, it is possible that the level of action of the Lean Construction Specialist may comprise design management, construction management and contract management. Accordingly, one or more building agents should be appropriately incorporated into the LOE according to their functions and responsibilities and based on the levels of action of the Lean Construction Specialist. The creation of the following agents is proposed: Design Manager, Construction Manager, and Contract Manager, definitions that are developed in this work. These agents are loosely defined, since any Project Manager, Building Information Modeling (BIM) Manager or similar, may act as one or as more than one of them. Finally, the creation of the Lean Construction Manager is also proposed, as the agent that takes on the role of the Design Manager, Construction Manager and Contract Manager, but focused on the Lean Production principles.

Keywords: Construction Manager; Contract Manager; Design Manager; Lean Construction; Regulation

1. Introduction

1.1. *Lean Production and Lean Construction*

The Toyota Production System (Lean Production) designed cars based on specific requests by their clients, made significant effort to reduce the time it takes to set up the machine and improve the quality management. It also developed three desired outcomes for the production system: to provide the costumer with the highest quality vehicle that also satisfies the customer in every way, to reduce response time, and as such defining a "just in time" approach, and supplying what it's needed when it's needed, and as such eliminating waste [1]. All this, in an environment that encourages collaboration between the company itself and independent suppliers based on prior agreements that were, in practice, collaboration contracts.

Since Laurie Koskela published his technical report TR72 in 1992, giving rise to the Lean Construction, this trend has evolved [2]. According to Koskela [3], due to these traditional managerial principles, flow processes have not been controlled or improved in an orderly fashion; this has led to complex, uncertain, and confused flow processes, expansion of non-value-adding activities, and reduction of output value. Koskela defined Lean Construction as *"a way to design the production system to minimize the waste of material, time and effort, in order*

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to generate the maximum amount of value" [3]. It also mentions that the information and the flow of material, as well as the method of operation in design and construction have to be measured based on waste and their added value.

1.2. *Last Planner System (LPS)*

LPS comes from combining the central elements of task management and flow management in order to control the production in all areas of construction, and as such improving their performance [4]. LPS is a production planning system designed to produce predictable work flow and fast learning in terms of programming, design, construction and commissioning of projects [5]. LPS was developed by Glenn Ballard and Greg Howell and has five elements [6]: (1) Master Scheduling; (2) Pull planning; (3) Make Work Ready Planning; (4) Weekly Work Planning; (5) Learning.

1.3. *Lean Project Delivery System (LPDS)*

In 2000, Ballard [7] stated that the LPDS emerged from theoretical and practical investigations, and was in a process of on-going development through experimentation in many parts of the world. *"In recent years, experiments have focused on the definition and design phase of projects, applying concepts and methods drawn from the Toyota Product Development System, most especially target costing and set based design. ... it is necessary to understand customer purpose and constraints expose the customer to alternative means for accomplishing their purposes beyond those they have previously considered, and to help customers understand the consequences of their desires. This process inevitably changes all the variables: ends, means and constraints."* [8].

1.4. *Target Value Design (TVD) and Integrated Project Delivery (IPD)*

"Target Value Design (TVD) is a disciplined management practice to be used throughout project to assure that the facility meets the operational needs and values of the users, is delivered within the allowable budget, and promotes innovation throughout the process to increase value and eliminate waste. Target Cost is the cost goal established by the delivery team as the "target" for its design and delivery efforts." [9]. IPD is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication, and construction [10]. IPD is an approach of an relational contracting, focusing on the projects main objectives and the major stakeholders, developing an organization capable of applying the principles and main practices of LPDS [11]. The team is invited to participate within a flexible contractual management framework, aimed at building Win-Win relationships of trust. Once the team accepts, it starts interacting through a collaborative routine in which BIM tools are used, which in term will allow to analyze each alternative posed by the stakeholders, seeking not to exceed the target cost of each stakeholder in the event adjustments are required. IPD, TVD and BIM are used simultaneously [2].

1.5. *Regulating Lean Construction*

"Project & Construction Management" is a practice with international recognition, regulated in United States, as well as United Kingdom, France and Germany [16]. However, each country has contractual restrictions as set in current legislation, in regards with different types of projects, procedures, contract models and forms original to each country or state, or developed to a extend, according to the kind of the construction. The "Lean Construction" agent is internationally renowned, not yet regulated, and it's very much "in" all over the world, in countries as United States of America, United Kingdom, Brazil, Australia, France, Germany, Chile and Peru, among others. However, depending on each country's regulation, its responsibilities can overlap with other specialists focused mainly in design or the project's execution. The main objective of this research is to standardize the Lean Construction agent within the Building Standards Act (Ley de Ordenación de la Edificación, LOE by its acronym in Spanish) in Spain. This could also work in other countries, in Europe or the world, that are in a much similar situation at the moment.

2. Spanish Regulation and Jurisprudence in Civil Jurisdiction

According to Antonio Humero [12], the LOE [13], as per result of a long-term experience process, garners only figures that have been appearing in the construction sector since the final draft of the Civil Code [14] until late last century; therefore, it does not consider other international movements and trends that have been included in such an area, such as: Project Manager, Facility Manager, Construction Manager, Safety Manager, Risk Manager, Design Manager, and others. Leaving the need of a continuous upgrade of the law, in order to adapt to the changing reality of the real state area. Because it does not exist any type of regulation in Spain regarding the agent in Lean Construction, contracts can be made defining such a special kind of agent in construction. The "Lean Construction" specialist is hired by other agents that deal in areas similar and related to those in "Project & Construction Management", and both agents' responsibilities can overlap as if they were "construction manager" or "design manager". It's because of the amount of advisers, specialist and agents that participate in the design and execution of the construction process that it's necessary a regulation for this agent when it participates in each stage of the project. In the other hand, there's jurisprudence from the Supreme Court [15] that might serve as legal base to establishing a specific regulation within the LOE for the "Project & Construction Management" agent [16]. This, too, can considered as the "Lean Construction" agent.

3. Methodology

3.1. *LOE Analysis*

Requirements are analyzed for all different agents that participate along the construction process, out of which we can derive the responsibilities. We also analyze the Spanish Civil Code, and which doctrines still applies. The agents detailed in the LOE include the safety and health coordinators, during the elaboration of the safety and health study as well as during the execution of the building.

3.2. *Lean Construction agent analysis*

It's important to note that within the Spanish market the "Lean Construction" and "Building Information Modeling (BIM)" specialists do exist as such [17]. We will proceed to analyze the different meaning and impact that the Lean Construction specialist has, according to its evolution.

3.3. *Jurisprudence analysis*

Jurisprudence on the construction manager is examined, as dictated by the Justice Supreme Court, and it might even "reach" or "absorb" the Lean Construction specialist. To obtain the jurisprudence, searches have been conducted in Spain's Judicial Power's website [15], in the Justice Supreme Court section, using keyword combinations such as "Building Standards Act", "constructive manager", "construction manager", "design manager", among others. Under the label "constructive manager", which is an interpretation of article 1591 of the Civil Code [14], the Supreme Court has already dictated civil responsibility against agents that, in all manners, function as Project Manager or similar, which is in direct relation to LOE indication, and will be further detailed in the next chapter.

4. Results and Discussion

4.1. *LOE Analysis*

For all different agents that partake along the construction process, all obligations are detailed and accounted for, of which we can conclude their responsibilities, detailing the building contractor as the person or company that guarantees the movement of the whole process and whose responsible for quality and material damage that the building might sustain. Within the building contractor's activities and responsibilities, the onsite manager has a special mention, as well as the obligation of ensuring all subsequent contracts are made within the law. The framework of the law also defines the behavior expected of such agents, as is the project designer, the owner of the site, the execution manager, stabilizing as such their responsibilities. There are other agents also related to those before indicated in LOE, which are defined in the Article 2 of the Royal Decree 1627/1997 regarding Construction Site Safety and Health [18], mainly the Safety and Health Coordinator during the elaboration of the project, and the Safety and Health Coordinator during the execution of the project.

LOE's Article 17 defines that the legal responsibility of the different agents for property damage liability in a building would be personal, meaning focus on one agent, based on their own actions or on someone else's that such person is responsible for. Joint liability would be required when responsibility for such actions cannot be narrowed down to one person, or when responsibility is due by the actions of more than one agent, or such responsibility is in any way joined by those agents [13]. LOE's *Seventh additional disposition, Sue notification request for other agents* [13], it speaks of the "third party intervention principle in legal proceedings, requested by the defendant", indicating that "a person who might end up sued as a result of actions or liability based on the obligations of their intervention of the construction process, and purview in the present law, might request, within the time limit the Civil Prosecution Law grants to answer the sue, to notify one or more agents that had had intervened in such process". Regarding the liability time limits, they are set in groups of one, three and ten years, depending on the different kind of damage done to the construction. The building contractor, during the first year, is responsible for all material damages done to the building because of poor execution; every agent that intervened in the project would be liable for up to three years for damages done to the building, caused by latent defect or defects that affect the building; and for up to ten years, for damages resulting from latent defect or defects that affect the building's structural integrity.

On the other hand, in Article 1, Section 6, the Spanish Civil Code indicates that the jurisprudence will complement the judicial order with the doctrine that the Supreme Court might establish interpreting or applying the law, practice and general principles of the law [14]. This means that the Supreme Court is the highest authority in applying the jurisprudence, based on the lack of the specific judicial order.

4.2. *Analysis of the Lean Construction agent*

When the Lean Construction persona appears, as it has been happening in many countries where the trend has taken over, this agent is usually an outside consultant of the owner, different from the agents already included in the law and to the Project Manager, that advises in the organization of the construction work, applying the principles, tools and system techniques. Likewise, he/she can advise the owner in any phase of the project, in the design management, contract management, and material execution management, therefore, they are a figure that has functions and related tasks that, many times, overlap with those of the Project Manager and other agents. When the first evolution of Lean Construction happens, including in such the LPDS, an additional figure is created, that we can define as the design manager, that partakes in the Project Definition and Lean Design phase, including in such the tools, techniques and practices of this philosophy to design the project, ensuring that the needs and requirements of the stakeholders are considered in the design alternatives, selecting the alternative that best suits the purpose and needs of the project, and including the Lean Construction practices from the initial phases. When the second evolution of the Lean Construction philosophy, creating the TVD-IPD, appearing a new figure that we could name in a general way as the Contract Management. This agent, as requested by the owner, collaborates with him in the construction project management, focused on optimizing the contract management in all the phases of the project, in a way that such contracts are a full collaboration. This agent runs and manages the other agent's contracts' processes in all the phases of the construction project. Finally, we conclude that the Lean Construction agent can be created, that they will take upon themselves the design management, the construction management and/or the contract management, as per required by the needs of the project.

4.3. *Jurisprudence Analysis*

We searched and analyzed in the jurisprudence about constructive managers as dictated by the Justice Supreme Court, which could "reach" or "absorb" the new construction agent, the Lean Construction specialist. In order to obtain the jurisprudence, we conduct a search in Spain's Judicial Power Web [15], in the section Justice Supreme Court, and we use the combination of keywords such as "Building Standards Act", "constructive manager", "construction manager", "design manager", among others, obtaining , an statistical population of 186 samples, of which only 17 are considered most important for being the closest related with the possible figures of the Lean Construction specialist, that could be determined by the Supreme Court. Table 1 shows the summary of the analysis.

As it's noted on the item 4.1 LOE Analysis, Section Seventh [13] leaves open the possibility that, of the agents that might be indicted, among them the owner, the building manager and the project manager, the construction manager, the onsite manager, the health and safety manager during the design of the project, and the onsite health and safety manager, and the onsite manager might request, during timeframe the Persecution Civil Law [19] grants to answer this sue, that this they might notify one or other agents that might have intervened in such process. Evidently, in case the Lean Construction agent might not be initially charged as responsible in the building process, it is very like that one of the other agents might request he'd be indicted as well, as he will have advised them on "alternative solutions" than those they were used to.

Table 1: Commentaries on Supreme Court's main rulings on constructive managers

Nª	CODES	CONTENT	COMENTS
1	STS 1256/2004	Constructive manager's liability regarding his actions as Site Manager	The "Lean Construction" specialist works directly with all other specialist and could be confused in that way.
2	STS 2071/2001	Constructive manager's liability as he coordinated, supervised technical matters and made decisions on site.	The "Lean Construction" specialist can perform in this area.
3	ATS 5879/2011	Constructive manager's liability as he participated in other agent's functions.	The "Lean Construction" specialist interacts with other specialists.
4	STS 2676/2009	Responsible as cooperative manager, or owner association manager, or similar	The "Lean Construction" specialist can be included in this area, if he were part of the project from the beginning.
5	STS 1726/2015	Free of Responsibility as cooperative manager or owner association manager or similar.	The "Lean Construction" specialist could be included in this area if he were part of the project from the beginning.
6	STS 4524/1994	Absolved of all responsibility for construction defects.	The "Lean Construction" specialist interacts with other specialists could initially be included in this area.
7	STS 4650/1979	Responsible for damages to third parties and large loses and with interrupted electric supply.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
8	STS 5950/2009	Responsible for damages in the delayed completion date of the apartments, and agents should be sued equally to all those that participated in the project, in order to correct all damages.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
9	STS 6563/2011	Responsibility for damages to third parties for unexpected settlement of the neighboring building, of one or more owners, or similar	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
10	STS 7941/2006	Responsibility for latent defect or construction defects.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
11	STS 8112/2007	Responsibility for damages in the delay of completion date, and all parties should be equally parts liable pending correction of all damages.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
12	STS 8151/2004	Responsibility for latent defect or construction defects.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
13	STS 8710/2007	Absolved of all responsibility under the name of manager or cooperative manager, or owner association manager or similar.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
14	ATS 756/1998	Responsibility for latent defect or construction defects.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
15	ATS 960/2007	Responsibility as cooperative manager, or owner association manager or similar.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
16	ATS 1769/2014	Responsibility for latent defect or construction defects.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.
17	ATS 4007/2014	Responsibility as cooperative manager, or owner association manager or similar.	The "Lean Construction" specialist interacts with other specialists and could be included in this area.

4.4. *Incorporation of the Lean Construction agent proposal*

In this investigation, we have established that the Lean Construction's agent influence, in the design, as per LPDS, TVD or IPD, as well as in the execution itself, can overlap with that of other agents such as the design manager, site manager, construction manager, and safety and health manager during the design of the project, safety and health manager during construction, and onsite manager. Considering that the jurisprudence shows that the law has previously held the "constructive managers" liable, a figure much similar to that of the Project Manager, due to the fact that it acts alone or in association with them, is understandable that because their responsibilities aren't quite clear, the court might also find the Lean Construction professional liable as well for such work.

Ergo, we propose the following construction agents to be added in the LOE:

- The design manager, operative agent that, as requested by the owner and working based on the technical standard, should work alongside the owner in the coordination and managing the agents.
- The construction manager is the chosen agent that, as requested by the owner and working based on the technical standard, works alongside the owner on managing the site manager, execution manager, the onsite health and safety manager and the onsite manager.
- The contract manager is the chosen agent that, as requested by the owner and working based on the technical standard, works alongside the construction and project manager, with the purpose of improving the contract managing in all areas or project stages.

None of this agents is held accountable, in any way or form, in Article 19 of LOE, Guaranties in case of compensatory damage for construction defects. Under no circumstances their actions are to overlay with that of other agents, especially those of the design manger, site manager, execution manager, health and safety manager during the project design, health and safety manager during the execution of the project, and onsite manager. These agents will decide, finally, if the advice given will be taken into account in their actions, under their own responsibility.

5. Conclusions

The duties of the Lean Construction agent might overlap with that of the design manager, responsible for the execution of the project, and even with those of the safety and health project manager. It's of vital importance to regulate this agent, because their responsibilities can be easily mistaken by those of other agents in the construction business. It's of main importance to regulate the construction process, updating and filling in the legal configuration of the agents that intervene in all aspects, separating their obligations in a way that we can define without a shadow of a doubt their own responsibilities, based on a clear definition of a building's basic requirements. In Spanish jurisprudence, we've been able to define some rulings that speak of the "constructive manager", an agent not yet regulated, and who has a combination of functions and obligations already regulated by the LOE to other agents under their own name. In this article, we've confirmed that the agent named "constructive manager", defined in jurisprudence, will broaden at the diversity of agent that start surfacing in all aspects of project. Given everything explained before, it is of vital importance that the "Lean Construction" agent be regulated, in accordance with the positions of Design Manager, Construction Manager and Contract Manager in the Spanish standards in regards with the legal void it holds now.

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Determination of Combined Rate of Overhead and Markup in Bid Price

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Abstract

The bid price for a construction project comprises the contractor's estimated direct cost and overhead cost plus its applied markup. Contractors often use an all-in rate to lump overhead and markup together on top of direct cost for arriving at a bid price. Such a simple method is naturally prone to inaccuracy, if the applied rate is selected subjectively. Contractors often have to cut their bids to increase the chance of winning, which however also increases the risk of making a loss. Using a combined rate of overhead and markup in competitive bidding without a sound approach certainly involves a greater risk. The present research aims to develop an improved approach to determining the combined rate of overhead and markup in the bid price for a project. Four factors, i.e., direct cost, duration, type of work, and location, were used as inputs to build a regression model from cost and bid data of 182 projects for predicting the combined rate of overhead and markup in the winning bid for a project, which, together with the model error, is used to estimate the probability of winning for a bid level. Then, based on minimization of overall loss risk proposed by a previous research, the bid preventing over-cuts in price competition is determined by comparing various bid levels using the model, the probabilistic estimates of project cost, and the probability of recovering costs if losing the bid. The approach is illustrated using an example. Comparisons of the suggested bids for the cases with those from other models are made.

Keywords: bid, markup, overhead, regression; risk.

1. Introduction

The bid or contract price for a construction project comprises the contractor's estimated direct cost and overhead cost plus its applied markup, i.e. profit. The contractor's direct cost refers to all expenses for labor, equipment, materials, and subcontracts directly connected with completion of the elements of the project as required by specifications and regulations. The contractor's overhead cost consists of the site overheads for supporting a project, such as supervision, offices, utilities, and services, as well as the project's share of the home-office overheads for running the firm, such as corporate management, procurement, financing, and marketing. The profit portion of the bid price is business-oriented and a higher or lower level may be charged as deemed appropriate.

Since direct cost constitutes the greatest part of a bid, it draws most attention of contractors. The site overheads can be estimated based on a construction program, as recommended by McCaffer and Baldwin [1], Diamant [2], and CIOB [3] etc. However, such detailed estimation is time consuming and not favored by many contractors, who often exercise their experience-based judgment and use a selected rate of estimated direct cost to cover all site overheads. A project's share of the home-office overheads is usually determined simply as a fixed rate according to the ratio of the firm's annual total home-office cost to its annual total revenue. Similarly, the profit charged for a project is usually determined also as a rate based on the conditions of the project, the firm, and the market. Thus, contractors often use an all-in rate to lump overhead and profit together on top of direct cost for arriving at a bid by using Eq. (1):

$$b = \bar{d} + \bar{o} + p = \bar{d} \times (1 + \frac{\bar{o} + p}{\bar{d}}) = \bar{d} \times (1 + r) \qquad (1)$$

where b = bid price; $\bar{d}$ = estimated direct cost; $\bar{o}$ = estimated overhead cost (site overheads plus project's share of home-office overheads); p = charged profit; r = combined rate of overhead and profit applied in b.

In Eq. (1), 1+r equals the ratio of bid price to estimated direct cost ($b/\bar{d}$). Thus, with $\bar{d}$ and r established, b is obtained readily. Despite the advantage of giving a quick result, such a simple method is naturally prone to inaccuracy, if the applied rate (r) is selected subjectively. Because project owners usually award a construction contract based on the lowest bid, intense price competition is common and contractors often have to cut their bids to increase the chance of winning. However, cutting bids undoubtedly increases the risk of making a loss in completing a job, if the winning bid is exceeded by the actual total cost. Using a combined rate of overhead and markup in competitive bidding without a sound approach certainly involves a greater risk for the contractor.

Because the time available for preparing a bid usually is short, the all-in-rate method represented by Eq. (1) is widely used by contractors in bidding. To avoid suffering an unworthy loss as a result of haphazardly applying an inadequate r, they should evaluate the impact of reducing r on the increase in loss risk against the increase in the chance of winning. However, although topics on bidding and estimating in construction have attracted much research interest over the years, the question of how to select a suitable r for a project has not yet been addressed. The present research aims to develop an improved approach to determining the combined rate of overhead and markup for a project in competitive bidding. The proposed approach is built upon previous researches by Chao [4] on overhead rate estimation and Chao and Liou [5] on bid-cutting limit determination.

2. Review of Literature

Existing bidding models focus on bid markup determination. In conventional models such as Carr [6], the markup rate is suggested as one with the maximum expected profit, where the expected profit for a markup rate is defined as the product of it and its probability of winning. Theoretically such a markup rate will achieve the highest profit in the long term, but it tends to give too low a chance of winning for contractors in intense competition, who often sacrifice profit in order to raise the chance of winning. Ahmad and Minkarah [7] took the lead in conducting a comprehensive study of factors influencing the markup decision. Others followed, for example, Chua and Li [8] identified key factors affecting bid-reasoning sub-goals. Meanwhile, various multi-criteria markup models built upon identified factors have been proposed, e.g. the multi-attribute utility model by Dozzi et al [9], the case-based reasoning model by Chua et al [10], and the fuzzy neural network model by Chao and Liu [11]. They offered various methods for producing an optimum markup for a project, yet they did not determine how low a bid could be and provide a rational solution in line with market conditions in which bidding competitively is imperative to survive.

Chao [12] proposed a fuzzy-logic-based model for determining the minimum bid markup that incorporates the position of a decision maker in the fuzzy rules. Chao and Liou [5] developed an approach to determining the lower limit of the bid markup based on minimization of the overall loss risk defined by a probabilistic model. In contrast to conventional models based on maximization of expected profit, these two models considered the chance of winning versus the risk of making a loss in evaluating various bid levels for solving the bid-cutting limit problem. However, as markup models, they did not include the contractor's overhead in the scope of their studies and neither did they establish a connection between project attributes and a bid's probability of winning.

Means [13] presented fixed overhead rates for field supervision, office, etc. and total overhead rates for various trades of subcontractors; however, it serves only as a manual because no method is provided. A case-based reasoning model for supervision cost estimation was developed by Chen et al [14] based on collected building projects, but it did not cover other overheads. More recently, Chao [4] developed a decision support system approach using a model for estimating the overhead rate from four project attributes, but it did not cover the markup rate to be applied in a bid.

3. Description of Proposed Approach

To determine a combined rate of overhead and markup (r) to be applied in a bid for a project, the probabilities of winning for various r have to be estimated. Consider that a contractor is bidding for a project in a market. When its estimated direct cost ($\bar{d}$) for the project is established, the bid decision reduces to determining r, so that a bid b equals $\bar{d}\times(1+r)$. To obtain an estimate of the probability of winning (P_w) for an r, recent bids in the market will have to be used, as these bids are indicative of the expected competition level. There are a few estimating methods and one of them is based on assuming a normal probability distribution for the lowest or winning bid (b^*) [10]. The estimate of P_w for r applied on top of $\bar{d}$ can be made as a parallel to that of the probability of winning for a markup rate applied on top of total project cost. By collecting a sample of projects and using the sample mean and standard deviation of $b^*/\bar{d}$ as the estimated parameters of the distribution, P_w for a bid b with $b/\bar{d} = 1+r$ can be estimated, without considering influences of varying project attributes such as project size and duration.

In order to give more accurate estimates of P_w, the estimation can be connected with project attributes by a multi-input model. Chao [4] developed a model using four project attributes, namely project size, duration, location, and type of work, as inputs for estimating the overhead rate in bidding. Since factors influencing the overhead level may also influence the markup level, the same inputs are used to build a regression model establishing the relationship of the combined rate of overhead and markup in the winning bid for a project ($\bar{r}$) to the project attributes. For a project faced, $b^* / \bar{d}$ is predicted at $1+\bar{r}$. The model can be built from the attributes, direct cost estimates, and winning bids of projects that a contractor bid for recently. Whether it has won the project or not, the perceived combined rate of overhead and markup in the winning bid b^* of a project ($\hat{r}$) is calculated as $\hat{r} = (b^* - \bar{d}) / \bar{d} = b^* / \bar{d} - 1$. The root of mean squared error (*RMSE*) is used as error measure, which is defined by:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\bar{r}_i - \hat{r}_i)^2} \tag{2}$$

where n = number of projects; $\bar{r}_i$ = $\bar{r}$ from the model for project i; $\hat{r}_i$ = $\hat{r}$ for project i.

Then, the model output $\bar{r}$ for the project is used to estimate the mean of $b^* / \bar{d}$ as $1+\bar{r}$. Next, assuming that $\hat{r}$ is normally distributed around $\bar{r}$ and since the variance of $\hat{r}$ is equivalent to that of $1+\hat{r}$, the standard deviation of $b^* / \bar{d}$ is estimated using the *RMSE* of the model. Therefore, P_w for a bid with $b / \bar{d}$ = $1+r$ can be estimated using the Excel function below.

$$P_w = 1 - \text{NORMDIST}(1+r,\ 1+\bar{r},\ RMSE,\ \text{TRUE}) \tag{3}$$

Chao and Liou [5] developed an approach to determining the bid that prevents over-cuts in bidding for a project. First, set the timeframe for analysis within the duration of a project (D) a contractor is bidding for. If the contractor wins with a bid b, there is a probability that the contractor completes the project without making a loss (P_n) because the actual project cost is lower than b. If the contractor does not win the project, the contractor will continue seeking other jobs and there is a probability that the firm wins other contracts during D and is able to recover its costs without making a loss (P_o). At the time of bidding, the expected probability of not making a loss ($\bar{P}$) is defined by P_n and P_o, the two consequences of bidding, weighted by P_w and $1-P_w$, respectively, as:

$$\bar{P} = P_w \times P_n + (1 - P_w) P_o \tag{4}$$

The approach is to evaluate $\bar{P}$ for various b in order to find out a bid $b^{\#}$ with a combined rate of overhead and markup ($r^{\#}$) that maximizes $\bar{P}$, i.e. has the highest overall probability of not making a loss. The bid $b^{\#} = \bar{d} \times (1 + r^{\#})$ is taken as the suggested bid. To evaluate P_n for a bid b, we start by estimating project cost ($\bar{c}$) using Eq. (5):

$$\bar{c} = \bar{d} + \bar{o} = \bar{d} \times (1 + \frac{\bar{o}}{\bar{d}}) = \bar{d} \times (1 + \bar{r}_o) \tag{5}$$

where $\bar{d}$ = estimated direct cost; $\bar{o}$ = estimated overhead cost; $\bar{r}_o$ = estimated overhead rate.

In Eq. (5), $\bar{r}_0$ is to be produced from the model in Chao [4] that maps overhead rates from project attributes, so as to obtain $\bar{c}$. Consider the actual direct cost (d) and the actual overhead rate (r_o) for a project as random numbers with the following relations to the actual overhead cost (o) and the actual project cost (c):

$$c = d + o = d \times (1 + \frac{o}{d}) = d \times (1 + r_o) \tag{6}$$

To obtain a probability distribution for c in Eq. (6), probabilistic estimating methods such as Diekmann [15] are used. The probability distribution for d is aggregated from the distributions for all work items. As a project comprises many items in various trades, the central limit theorem applies generally, the distribution of d is approximately normal, and so are that of c. The mean of c (μ_c) can be estimated using $\bar{c} = \bar{d} \times (1 + \bar{r}_o)$ from Eq. (5). Since d and r_o in Eq. (6) usually are not linearly correlated, σ_c^2 as the variance of $c = d \times (1 + r_o)$ can be obtained using Eq. (7).

$$\sigma_c{}^2 = \mu_d{}^2 \sigma_{1+r_o}{}^2 + \mu_{1+r_o}{}^2 \sigma_d{}^2 + \sigma_d{}^2 \sigma_{1+r_o}{}^2 = \mu_d{}^2 \sigma_{r_o}{}^2 + (1 + \mu_{r_o})^2 \sigma_d{}^2 + \sigma_d{}^2 \sigma_{r_o}{}^2 \tag{7}$$

where μ_d = mean of d; $\sigma_{r_o}^2$ = variance of r_o; μ_{r_o} = mean of r_o; σ_d^2 = variance of d.

In Eq. (7), μ_d can be estimated at $\bar{d}$ using the sum of mean direct costs for all work items and σ_d^2 can be estimated using the sum of variances of direct cost for all items (SV). For each item, the minimum, most likely, and maximum estimates can be used to form a triangular distribution, from which its mean and variance can be solved. Next, μ_{r_o} can be estimated at $\bar{r}_o$ from the overhead rate model and $\sigma_{r_o}^2$ can be estimated using the mean squared error of it (MSE_o). By standardizing c against $\bar{d}$, P_n for a bid with $b/\bar{d}$ = 1+r can be estimated using the Excel function below:

$$P_n = \text{NORMDIST}(1+r,\ 1+\bar{r}_o,\ (\frac{\bar{d}\wedge 2*MSE_o+(1+\bar{r}_o)\wedge 2*SV+SV*MSE_o}{\bar{d}\wedge 2})\wedge 0.5,\ \text{TRUE}) \qquad (8)$$

The last term in Eq. (4), P_o, the probability of recovering the contractor's costs from other contracts won within D, given losing the current bid, represents the firm's prospect in the near future. P_o close to 0 means poor prospect, i.e. few jobs and very low winning bids, whereas P_o close to 1 represents the opposite, excellent prospect, i.e. plenty of jobs and winning bids getting steadily high. The details on assessing P_o are given in Chao and Liou [5].

4. Illustrative Example

To illustrate the proposed approach, 210 recent public projects in Taiwan were collected from a contractor who bid for the projects in order to build a regression model for estimating $\bar{r}$ as the dependent variable. Four project attributes are used as model inputs or independent variables, i.e. project size represented by estimated direct cost ($\bar{d}$), duration (D), location, and type of work. With respect to location as well as type of work, a classification scheme was developed and binary representation was used. Whether the firm won or not, the winning bid (b^*) of a project was used along with its $\bar{d}$ to calculate the combined rate of overhead and markup in b^*, i.e. $\hat{r}=(b^*-\bar{d})/\bar{d}=b^*/\bar{d}-1$, for use as the target output. Next, a regression analysis was carried out on the 210 projects and the obtained R^2 of 0.158 shows poor explanation of variation of $\hat{r}$. An examination of the model errors reveals 26 projects with very large deviations from target outputs, indicating existence of other factors unique to them, and so they were discarded, resulting in a sample of 184 usable projects. Then, statistical analyses were carried out on the 184 projects, including descriptive statistics and correlations among the variables, whose results are shown in Tables 1, 2, 3, and 4.

Table 1. Statistics of $\bar{d}$, D, and $\hat{r}$ for the usable 184 projects (note: NT$1≈US$0.03)

	Minimum	Maximum	Mean	Standard deviation
$\bar{d}$ (NT$ million)	7.5	1253.3	154.8	188.7
D (day)	36	1095	457	191
$\hat{r}$	0.053	0.321	0.121	0.086

Table 2. Statistics of $\hat{r}$ by location

Location	Number of projects	Mean	Standard deviation
Taipei area (*TP*)	15	0.085	0.072
Other cities (*CT*)	88	0.124	0.082
Remote areas (*RMT*)	81	0.125	0.091

Table 3. Statistics of $\hat{r}$ by type of work

Type of work	Number of projects	Mean	Standard deviation
Pipelines (*PP*)	76	0.095	0.023
Site works (*ST*)	51	0.117	0.086
Roads (*RD*)	18	0.140	0.081
Bridges (*BRD*)	25	0.159	0.089
Buildings (*BLD*)	9	0.170	0.105
Ports (*PRT*)	5	0.216	0.099

Table 4. Coefficients of correlation among quantifiable project attributes

	$\bar{d}$	Duration	$\hat{r}$
$\bar{d}$	1		
D	0.593	1	
$\hat{r}$	-0.183	-0.065	1

The statistics in Tables 1, 2, and 3 show that the projects vary widely in size, duration, and $\hat{r}$ with large standard deviations and the mean of $\hat{r}$ increases with increasing project remoteness and complexity vis-à-vis location and type of work, respectively. In Table 4, $\bar{d}$ and duration are positively correlated, while $\hat{r}$ correlates with $\bar{d}$ and D negatively albeit weakly. The above appear reasonable from the viewpoint of construction management and economics principles, indicating suitability of the data for model building.

Two of the 184 projects, called Project A and Project B, were set aside for simulation of bidding. The remaining 182 projects were used to build a regression model of $\bar{r}$. The obtained model achieves a higher R^2 of 0.283 and an $RMSE$ of 0.07265, which is lower than the sample standard deviation of 0.086 in Table 1. It is shown below.

$$\bar{r} = 0.247 - 0.0002\bar{d} + 0.0001D - 0.0288TP + 0.0284CT - 0.1964PP - 0.1391ST - 0.1146RD - 0.0915BRD - 0.0756BLD \quad (9)$$

Using Eq. (9) and the attributes in Table 5, $\bar{r}$ is estimated at 0.145 and 0.109 for Projects A and B, respectively. Then, for each project, P_w for various levels of r are estimated using Eq. (3). Next, the standard deviation of direct cost is estimated at $0.05\bar{d}$ for Project A and at $0.04\bar{d}$ for project B, so the SV for the two projects are $(0.05\bar{d})^2$ and $(0.05\bar{d})^2$. The overhead rates for each project are estimated using the following regression model in Chao [4] that is parsimonious in inputs with an MSE_o of 0.00116. The obtained $\bar{r}_o$ are shown in Table 5.

$$\bar{r}_o = 0.18 - 0.023TP - 0.021CT - 0.1PP - 0.1ST - 0.093RD - 0.089BRD \quad (10)$$

Table 5. Attributes of projects A and B and cost estimates for them

	Project A	Project B
$\bar{d}$ (NT$ million)	153.64	82.73
D (day)	540	500
Location	TP	CT
Type of work	BRD	PP
SV	$(0.05\bar{d})^2$	$(0.04\bar{d})^2$
$\bar{r}_o$	0.068	0.059

With all needed parameters established for each project, P_n for various levels of r are estimated using Eq. (8). Then, for each project with poor prospect (P_o=0.25) and with average prospect (P_o=0.5), $\bar{P}$ for various level of r are assessed using Eq. (4) and the combined rates of overhead and markup achieving maximum $\bar{P}$ are determined as the suggested $r^\#$. The $\hat{r}$ perceived in the actual lowest bids, $\bar{r}$ estimated by Eq. (9), $\bar{r}$ estimated using the sample mean of $\hat{r}$, $r^\#$ suggested by the proposed approach with each prospect, and $r^\#$ suggested by the conventional model are compared in Table 6.

Table 6. Combined rates of overhead and markup for projects A and B

	Project A	Project B
$\hat{r}$ perceived in actual lowest bid	0.162	0.080
$\bar{r}$ estimated by Eq. (9)	0.145	0.109
$\bar{r}$ estimated using sample mean of $\hat{r}$	0.121	0.121
$r^\#$ suggested by proposed approach with poor prospect	0.120	0.102
$r^\#$ suggested by proposed approach with average prospect	0.136	0.116
$r^\#$ suggested by conventional model	0.151	0.146

For both projects, $\bar{r}$ estimated by Eq. (9) are closer to $\hat{r}$ in the actual lowest bids than those estimated using the sample mean of $\hat{r}$, so better accuracy in estimating P_w for a bid can be attained. The suggested $r^\#$ from the proposed approach are lower than those suggested by the conventional model that is based on maximization of expected profit, showing that it gives more competitive bids. However, no excessive loss risk is involved in applying the suggested $r^{\#}$ since the proposed approach is based on minimization of overall loss risk. Note that the suggested $r^{\#}$ are lower for both projects with poor prospect because of the effect of smaller P_o, which makes the project being bid for more important as discussed in Chao and Liou [5]. Note also that $\hat{r}$ in the actual lowest bid for Project A being higher is due to the random nature of bids received.

5. Conclusions

Contractors often apply an all-in rate of overhead and markup on top of the estimated direct cost for arriving at a bid, but this practice involves a greater risk if the rate is selected subjectively without a sound basis, especially so when price competition is intense. The proposed approach in the present research is based on building a model for estimating the combined rate of overhead and profit in the winning bid for a project from four project attributes as well as determining the optimum rate in a bid for the project in order to achieve minimum overall loss risk while keeping competitiveness. The proposed approach can help prevent over-cuts in bids under intense price competition and help enhance the construction industry's performance by reducing contractor failures. The approach's practicality will be studied further in the future in order to provide suggestions for practitioners when using it.

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Creative Construction Conference

Three Entities to Maximize Creative Construction Quality

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Abstract

Creativity in construction is somehow intrinsic to the nature of designers. Never, as today, was there such a demand for newness. In Portugal, the situation is no different, where there is a body of young professionals eager to unveil a reality never before attempted or, simply, unknown to them. The momentum supports their motivation to experiment, with greater or lesser awareness, though not always with the desired results, either for lack of: training; information; handling of materials and products; openness of the Project Owner; specific and cross-cutting knowledge of other sciences (present in the maturation processes / sinterization solutions); accuracy in the use of technical terminology; professional and productive environment; test systems, prior validation, construction methodology, approval, robustness assessment, assurance and documentation for registration.

At times, news about the construction sector are disconcerting, even on outstanding works that evoke architectural creativity - supported by creative construction - as a purpose. Those are often awarded in international competitions, of recognised merit, by partners, operators and future professionals.

The creative construction, by principle, is based on the reassessment dogmas! This statement, in the reality of contemporary construction, widely systematized, may translate into an overwhelming success but also into its opposite. The repetition of a defective solution can lead to the collapse of the whole, exponentially. Only a system equipped with tools that allow control over the decisions, in the different stages, can prevent failure, through the evaluation of those and consistent report on their impact, particular and overall. The involvement of fundamental entities, in the different phases, makes it possible to anticipate the robustness of the solution, a.k.a. creative construction, by the different operators, with general skills in diverse areas of knowledge, such as: assessment, monitoring and validation in the design stage or construction work; and assumption of guarantees, including corrective, if need to minimize the overall impact.

Keywords: construction; guarantee; products; roughness tests; certification and approval; labs.

1. Introduction

The need for protection against the natural elements led men to build shelters. In a slow, pondered and reflected-upon technological evolution which later asserted itself as popular architecture. Such evolved towards the maximum efficiency with no room for lack of value. Measured by trial and error, over the years, in a successful dichotomy. Knowledge - informally - transmitted from master to apprentice, reached another level with the development of manuals associated with theoretical and practical training.

The incessant search for novelty is intrinsic to designers. Through the supremacy of the solution. Be it for the simple conjunction of formulas or merely for the application of a theory: in short, the art of construction. On the one hand there is the need to innovate, overcome, demonstrate and present findings to peers, on the other the risk of possible failure by lack of knowledge, unconsidered, it is real and can ruin a construction solution. This may be mitigated by further research: access to information is now universal and, mostly, free. There are, however, other channels - so-called traditional - such as Detail Magazine (architecture detail), a monthly publication of excellence for the design / construction.

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The globalized world tends to relate to those themes indistinguishably. In Portugal, the situation is no different: almost everyone searches for novelty, at any cost, in order to surprise others, either through innovatively materials conjugation, by importing a constructive methodology or the use of "new products" (local or otherwise).

2. Context

2.1. *Situation*

Creative construction is, by conviction, the attitude of questioning dogmas, prevailing standards and preconceived truths. This requires will and courage, which we must all recognise. This determination applied to the largely systematized contemporary construction could lead to an overwhelming success. But also its opposite, as the repetition of a flawed solution, from the outset, can lead to the failure of the whole, in an exponential way.

Creative solutions are possible based on merit, technical and artistic or technical-commercial, proper or derived from stimulus (e.g., publications, exhibitions, lectures, conferences, among others). They embody an appeal to the advancement / development in construction, to which most designers capitulate before the solution geniality - believing that thus will become the author / product that we all recognize by the option that consecrated him/it. However, despite the immediate success there is a tendency that after an ill-considered decision problems arise with high maintenance costs and no practical solution, as shown by the examples included in this article. The problems even if detected tend to be ignored (e.g., designers, general contractor, project owners, et cetera), with the exception of the operator and end users. By the former, when problems interfere with proper functioning; and the latter - with no direct ability to solve them - through ongoing interaction with the resulting constraints.

In Portugal - with professionals with an average age around thirty years *[Manuel Villaverde Cabral, coordinator, and Vera Borges, "Relatório Profissão: Arquitecto/a", a study sponsored by Ordem dos Arquitectos, INSTITUTO de CIÊNCIAS SOCIAIS, UNIVERSIDADE de LISBOA, Lisbon, November 2006.]* - it is required a dynamic domestic market and that the industry (European, North and Central) is sensible to their desires. Currently, both seek to meet the needs and global values, conditioned by the hegemony of the countries with strong financial hold. This allows to accommodate and promote research centers to develop "innovative products", welcomed with great enthusiasm by professionals. The allure for newness makes them "exciting for any project", a situation that tends to divert attention from the real technical characteristics, which can trigger degenerations (both physical and chemical reactions), and the environment in which will be inserted (environment, techniques learned, construction means, et cetera), eg, when mixed with standard materials and building products.

2.2. *Reasons*

"At the City of Arts and Sciences, a huge project by Santiago Calatrava in Valencia, Spain, work is under way to fix problems that have cropped up since the project was built." by Samuel Aranda for The New York Times, about the same issue, "What you see over and over again is that rather than searching for functionality or customer satisfaction, he aims for singularity," said Jesús Cañada Merino, the president of Bilbao's architects' association. [by Suzanne Daley on 24/09/2013, under Art & Design" section, entitled "A Star Architect Leaves Some Clients Fuming - Santiago Calatrava Collects Critics as Well as Fans by Santiago Calatrava" published in "The New York Times", website.]

Excessive use of imported products - as it is the case in Portugal - can lead to extremely complex situations. With the logistics at the head of the problem: supply, rehabilitation and interventions. Issues that make it difficult to maintain the original qualities - losses enhanced by the degree of request (e.g., load) exerted on the solutions - with aesthetic and functional implications on all the systems. This condition has greater impact on public buildings, especially the ones with higher turnout, which tend to evidence an rapid wear, resulting in: widespread damage (eg, extension of areas, size of elements/parts and technical repair and specialty - infrastructure and networks); technically demanding maintenance; and difficult management of spaces / facilities. Building complexes, both contemporary and historical, are also vulnerable to the above described issues, with countless constraints (eg, transport of oversized loads - simple in the case of the current approach): not considered, by decision-makers, in the course of construction works.

Changes and adjustments during the design or construction phase are in principle reasons for the loss of quality and robustness. Those are related to the long development periods of projects, motivated by bureaucracy and / or legal approval processess: in a dynamic market, this leads to the replacement of products and the consequent appeal for novelty - a choice imposed, thus less weighted than the whole. Although these are often motivated by economic reasons their contribution can be very positive for the overall result. But if negative, can have serious implications on the remaining elements. It becomes imperative to validate decisions.

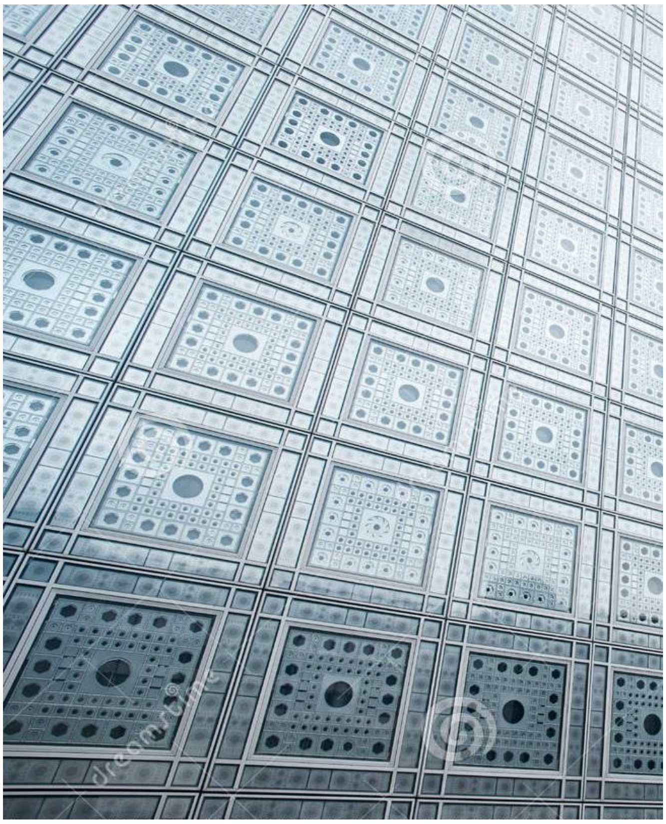
Workers in Valencia, Spain, fix leaking windows in a science museum by Santiago Calatrava, photo credit, Samuel Aranda for The New York Times.

Regarding coordination (projects - architecture and specialties), the technician in charge should be prepared to deal with the introduction of alterations:

- In general - symbiotic relationship - the system appears based on the solution and depends on it, and;
- In particular - antagonistic nature - the nature of the solution is not consistent with the general condition. The differences can cause complex problems, only understandable in the scientific field.

In the concession-construction process, due to the very short development period, should there be a need for adjustments they need to undergo a methodology based on reliable and tested data.

Specialities (infrastructures), by nature, are not predisposed to change and when subjected to them reveal dynamic problems, with transversal implications. These situations tend to reveal their full extent, during the use of the building, through constraints on the functions assigned to spaces, on the constructed elements and / or productivity of equipments, with impact to users.



"…the south facade of the building consists of high-tech photosensitive mechanical devices which control the light levels and transparency…

In 1980, 18 Arab countries concluded an agreement with France to establish the Arabic World Institute. The main purpose was to provide information about the Arab world and set in motion detailed research to cover Arabic and the Arab world's cultural and spiritual values.

The design competition was won by Jean Nouvel, who is widely known for his particular surface treatment with "smart" materials, and with this kinetic facade for the Arab World Institute, he designed a facade who responds to changing environments.

To achieve this, the south facade of the building consists of high-tech photosensitive mechanical devices which control the light levels and transparency.

It interprets traditional wooden Arab latticework screens into a glass and steel construction with 30,000 light-sensitive diaphragms on 1600 elements, which operate like a lens of a camera. The changes to the irises are revealed internally far more than what can be observed from the exterior.

The unique use of high-tech photosensitive mechanical devices made this building famous in 1987. Nowadays its still widely known and hasn't lost its futuristic impression, but the facade system no longer works." by Van Poucke on 31/ 01/ 2011, under History, Technology, Uncategorized, entitled "Arab World Institute by Jean Nouvel" published in "Kinetic Architecture" website.

2.3. *Products*

Trendy solutions, fostered by commercial strategies, are difficult to compare to the competition, since the advertised results represent a clear case of self-promotion. These do not strive for quality of the technical and scientific information and are not adjusted to local conditions, technologies and knowledge in the construction industry, which increases the responsibility of the technician collecting information to justify the option taken.

Technological and commercial gains justify the use of certain products, without raising questions about its efficacy (?!) - assuming the goal is to ensure the best price/quality ratio. European certification or approval of a product, with no rebuke, does not guarantee its robustness. The durability, expected or achieved, for a given country can not be guaranteed to another. Latitude, maritime proximity, industrial development, skills of the labor force and construction management are some of the constraints that undermine the certifications and approvals established by and for "Europe" - a recurrent situation in Portugal!

If we analyze the innovative products, or perceived as such, especially imported, we can conclude:

- Commercial/Business level - conditional technical data - through the use of non-current systems, shielded by non-European standards and approvals, difficult to understand - diffusion through promoters, always influential among decision makers, with an emphasis on superficial benefits (aesthetics), without any credible support to the information presented - problems only become visible / known after application (construction) and consequent exposure to the elements;
- Laboratory level - Approval / Certification - the introduction of new products requires assessment by accredited laboratories (eg, LNEC, ISQ - Instituto da Soldadura e Qualidade, among others), requested by manufacturers or their representatives - the results tend not to be disclosed or, if necessary, are adjusted by the interested parties to serve "commercial" purposes;

"In the specific case of paint, the results appear inflated by 30 percent, a clear discrepancy between the assayed and commercial information. The strength test is conducted in a controlled environment very different from actual/real conditions which are more complex, they tend to focus on the normative benchmarking, not always effective on solutions, particularly composite (combined or overlapping). The products when subjected to specific tests (e.g., chemical and biological attacks, wet and dry friction, wear from use and cleaning, sunlight exposure, mechanical erosion) with no time limit, show an offset performance, since the abuses occur simultaneously and

for long periods of time - with different intensities and fluctuating force cadences, revealing a natural degeneration adjusted to local conditions."

- Construction level - the application of a product or solution - after completion of the work, the natural degenerative process begins which may reveal some of the aforementioned issues, then it is possible to record degradation phases that reveal the amount and extend of damages, in cases where the solution is repeated across the whole (modular construction), the implications will be multiplied, creating a harmony of damages - repairable through specialized work with unweighted costs - with impact on the robustness of the buildings and therefore the industry that supports them; trial and error is ineffective for consolidating solutions, from the viewpoint of a promising technology.

3. The entities

From the authors point of view, creative construction, especially in qualitative terms, would benefit from the contribution of three entities:

- **Accredited/Institutionalized laboratories**, in Europe, already accredited to perform certifications and homologations - based on standards, conditional on payment - organised entities with capable and experienced human resources, supported by state-of-the-art equipment. Based on information available, could produce documents supported on standardised normative criteria, which are simpler to read and free to access - as it happens to documents on the energy efficiency of buildings and sections thereof, the basis for their public promotion -, online, the interested parties - manufacturers and distributors of materials or products - would assume the costs and information disclosure, to clarify and complement the commercial information, to increase the ability to communicate the actual features of the products / materials in order to inform the industry actors.
- **Universities / Colleges** are credible and independent institutions, recognised across borders on their merits in furthering scientific based knowledge. Equipped with means and resources, especially human, skilled, eager and capable of taking an active role in the analysis of the behavior and effects of the elements / constructive solutions, in a complementary way. It is recognized the commitment that modern societies do in research centers, often associated with educational institutions. However, there is a sense that those do not contribute sufficiently to solve real issues in their respective fields and to the improvement of various social systems - e.g., education, justice, security, health, economy, and more. In an effort to reciprocate the investment that societies do in them, innovative products could be assessed in an university laboratory environment. This possibility promises great scientific interest. Market players promote and share innovation. Students would take part - in a path that is starting - motivated to address these issues with minimal bias in the acquisition of knowledge, on applying rules and procedures in the test environment (robustness). Teachers would assess - through a scientific approach, of a practical nature - disseminate knowledge, the results would be debated widely with contribution to the improvement of the status quo.

Motivation is the key word. When we feel motivated we tend to ignore the passing of time, focussing on success and recognition.

[In the 90s, Bill Gates, founder of Microsoft, created an encyclopaedia - Encarta - with the participation of entities, recognised for their scientific merit regarding published content, and justly respected for their opinions. At the beginning of this new millennium a new concept appeared, founded by Jimmy Wales - "Wikipedia - an open source in which anyone could input their opinion, free and spontaneously, at the same time, the shared opinion was controlled by others of equal value and motivation for the debate. Thus was born and bred the largest human encyclopaedia. It is possible to dispute the quality of the shared knowledge, for not being validated by entities accredited for such, but it only depends on those, since they have the possibility to do so. Many already do it, others have their employees doing it. "Encarta" is just another moment in history and, by chance, in the memory of some.]

- In the system in place, the construction industry, there is a shortcoming regarding quality assurance - conclusion which results from research taken for other articles / studies. Risk analysis emerged as a new field of intervention in the system. At the moment there are no qualified technicians for this role, which could easy and quickly be taken by architecture and engineering graduates, currently in sufficient number to take on roles outside the traditional path (designers). Through a Master's level course, traditional or integrated, taught at faculties with the support of Instituto de Seguros de Portugal. Employers would be offices geared towards risk analysis or insurance companies. The risk analysts would work to ensure quality, covered by a insurance policy for the warranty period - freeing other parties to their natural responsibilities: promoter to promote, designers to design, supervision to supervise and the contractor to build. Specifically, risk analysis should promote testing even in the design phase, to control the accuracy/rigor of the implemented construction, with the intent to assess the quality and capacity with use. Less claims, more profit - from a market economy standpoint. The involvement of key entities such as risk analysts - as strengthened in "Risk Analyst: a new player in the construction processes - Portugal"** - allows to predict the performance of the solution, especially when dealing with experimental construction, with the following phasing:

a) design/project - assessing the proposed solutions - control and validation, design and implementation of test construction, and;

b) construction - checking the rigor of the chosen solutions, imposing corrective measures to minimize the overall impact, extrapolating the behaviour for the guarantee period, assessing the risk of degeneration, specific and general, and documenting the process.

"The structural problem of the Millennium Bridge is due to "synchronous lateral excitation", where the footfalls from pedestrians create lateral movements in the bridge. These movements are enhanced when the pedestrians attempt to compensate and match their footfalls to the bridge's movements. At more than 156 pedestrians this type of movement increased visibly in the Millennium Bridge. The structural problems were studied at the Cambridge University Structure Laboratory." and "Chronology: 10 June 2000 - On the opening weekend, over 150 000 people use the bridge. On Saturday, larger than expected movements are experienced as larger crowds cross the bridge; 12 June 2000 - The bridge is temporarily closed to assess the deflection problems that occurred in the first days of opening, and; 22 February 2002 - After addition of dampeners during a £ 5 000 000 repair program, the bridge re-opens to the public." by unknown author on unknown date, entitled "Millennium Bridge" by Norman Foster published in "Structurae" website.

4. Findings / Conclusions

The proliferation of ideas that shape brilliant insights, of artistic nature, at the level of construction which, when effective, are a success story - although naturally uncommon.

The standardization of technical documentation, a proven asset for the construction operators, with gains in communication and a decrease in misunderstandings, would allow proposals to be interrelated and the compatibility of products embedded in a solution to be verified, as well as their relationship with local and respective specificities.

The introduction of educational institutions is justified by their natural predisposition to acquire knowledge without profit as motivation, a position that would allow testing the degenerations on constructive solutions in collaboration with the producers / representatives in conditions similar to reality, but in a laboratory evaluation.

This research considers that bold construction processes, especially experimental, must be subject to procedures which ensure the control of efficiency and robustness, in a system able to identify and correct errors, for operational efficiency, overall comfort and safety. A construction quality control system equipped with tools - that allow the monitoring of decisions, by stages - can prevent failures, by evaluating the options, with the subsequent learning and reporting, for future reference.

Case study for this research/paper

Shading solutions - in this case, external shutters with metallic foil profiles (movable, with non aerodynamic blades) and brise soleil (fixed) - present low durability, since the strong wind gusts and intense sun exposure contribute to the fast degradation of petroleum-based materials (recurrently used due to low cost associated with them) which cause damages and occasional disengagement/detachment of elements, with possible risk to passersby.

The devices installed on the windows of the classrooms, of the Escola Superior de Comunicação Social from Instituto Politécnico de Lisboa, of an italian brand, sold through a national representative (importer), without the capacity to make repairs, condition which requires, in case of need, technicians to come from the country of origin of the products to the school, equipped with the necessary tools and accessories, with all of the costs and logistic means that entails.

The difficulty or even the impossibility of repair/maintenance resides in the mounting system, the little space available inside makes it difficult to operate/handle and the outside requires the use of lifting means.

Acknowledgements

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Impact of the Operational Expenditures on the Public Sector Procurement Process

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Abstract

Ever-changing needs in the built environment create new incentives for enhancements in the process of building design. Increasing prices of building operations and utilities have a profound impact on the conceptual design and implementation of sustainable architecture. The main aim of this paper is to present Life Cycle Cost Inspector (LCCI), which is a tool for assessing building design in regards to the whole asset life cycle and thus promoting sustainable solutions. LCCI is a quantitative comparator of the overall planned capital investment and the operational expenditures (OPEX) over a specific period of time. This method is based on dividing the selected project into separate components (e.g. heating, plumbing or ventilation) that have their own operational characteristics. Subsequently, projected cash flows are estimated over a chosen time period based on preferred criteria, square meters and a life span of each component. An additional feature of the comparator allows calculating vice versa, which means that the investment costs can be adjusted, based on the targeted operational performance of the asset, which could be directly specified.
As any other device, LCCI is based on a simple idea – to create a tool, which enables the owner to execute the present process more efficiently. Specifically, the main aim is to transform the given and limited resources into such product, which represents the highest value for money achieved, of course in regards to the process and human limitation.
The overall process of operational expenditures assessment and optimization of the capital costs indicates higher value for money achieved through sustainable architecture; and thus, advocates higher initial capital cost during the tendering process. Therefore, within this research, the traditionally perceived concept of the lowest cost selection is questioned and a new perception of value for money is introduced and applied within the quantitative comparator's environment.

Keywords: capital expenditures; operational expenditures; public sector; value for money

1. Introduction

The building industry is continuously facing economical, technological and social challenges. The recent financial crisis caused changes in overall perception of building projects' design and construction. Almost every stakeholder within the construction process is seeking to make savings and reduce costs. Building contractors are being forced to reduce their bidding cost in order to maintain their competiveness, whereas project owners are experiencing difficulties in renting their assets to tenants who are looking for buildings with low operational costs and rent.

The main aim of the LCCI is to present a comparative analysis of different investment options and further assess all costs related to the whole asset life cycle. This method takes into account not only the investment costs, but also all costs linked with the asset operation, maintenance and removal. The whole life cycle costs of a particular asset indicate the inevitable fact that the operational costs have the major impact on the investment effectiveness, which promote the aspects of the sustainable design.

Two main questions are addressed: What are the main obstacles in delivering sustainable buildings within the Czech public sector? How can the LCCI overcome the barrier to more sustainable design and investment options?

2. Overview of the Czech Public Sector Procurement

The Czech procurement process of construction works indicates strong focus on reducing capital expenditures and thus improving economic effectiveness of public sector tenders. To understand the true impact of the capital and operational expenditures on the construction projects financed by the public initiatives it is necessary to describe current public sector practices and the overall amount of resources, which can be affected. The total amount of resources allocated for the construction works are summarized in Table 1, which also divides the total amount of contracts according particular sector (supplies, services or construction works) [1].

Table 1. Overview of the Czech public sector contracts [1]

Contracting authority		Type of contracts			Total
		Supplies	Services	Construction Works	
Public authority	Value of public sector contracts in mil. Euros	4,929	1,036	3,321	259
	Value as percentage	53.2%	11.0%	35.8%	100.0%
Sector authority	Value of public sector contracts in mil. Euros	1,036	1,857	1,250	4,179
	Value as percentage	24.9%	44.8%	30.3%	100.0%
Total 2014	Value of public sector contracts in mil. Euros	5,964	2,893	4,571	13,429
	Value as percentage	44.4%	21.5%	34.1%	100.0%

3. Example of the comparative method

According to the current Czech legislation (public bidding and procurement law §78) there are two main criterions for evaluation the received bids:

- the overall economic impact, or
- the lowest bid price.

Tender evaluation based on the overall economic impact is scarcely used as since it presents a significant risk of possible disputes if not properly set. Thus, majority of public tenders for construction works are evaluated according the lowest bidding cost, which is straightforward and certainly defensible if any objections from other tenderers arise. Nonetheless, the lowest price criterion absolutely omits impact of the operational expenditures needed throughout the whole asset life cycle

4. Value for Money and Discounting

The overall economic impact of the public sector contracts can be assessed through the total value for money achieved for a particular contract/tender. This method is well known and frequently used especially for assessing economic effectiveness of projects delivered through alterative procurement methods such as partnership of the public and private sector. The aforementioned method empathizes importance to reflect the market cost of capital otherwise it could crowd out more beneficial private investment. It is argued that the timing of payments is economically significant because people value consumption today over consumption in a year's time or later. This is the time preference argument. Both these economic costs, the cost of capital and time preference, are expressed in a single rate known as the discount rate [2].

Discount rate is normally used for transforming the future cash flows into the present cash cost. However, taking into account the economic costs, the discount rate includes more than just time difference between the future and present value of money.

More than that, the discount rate also includes factor of uncertainty. Life Cycle Cost Inspector, which will be described more in detail later, takes into account the cost of some potential risks linked with constructions in general and applicable for particular building materials, processes or systems.

The discount rate is the key factor, which determines the present value of the future cash flows [3]. Nevertheless, calculating the present value creates a great challenge since there are various methods how to measure it. The key assumption is that the present value for money is worth more than the same amount in a few years later. This is caused by inflation and by a possibility to invest money with a certain interest rate now, which would ultimately lead to positive earnings in the future (but only for investment with the minimal risk possible).

In this case, Net Present Value is used and calculated according the following formula [4]:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} \tag{1}$$

where CFt is net cash flow in the time t
where r is discount rate
where t is time of the cash flow
where n is number of periods

Different investment options for different timeframes can be only compared when the time value for money is considered thus Net Present Value is used for each researched variants within the LCCI interface.

5. Life Cycle Cost Inspector

Life Cycle Cost Inspector (LCCI) is designed as a tool for qualitative and also quantitative comparison of several options in regard to their capital investment and subsequent operational expenditures and investments linked with the removing or disposal of the asset/service. Advantage of this tool is that it can be applied not only for works linked with construction but also for other disciplines such as procurement of ongoing goods, investments or services.

As any other device, LCCI is based on a simple idea – to create a tool, which enables the owner to execute the present process more efficiently. Specifically, the main aim is to transform the given and limited resources into such product, which represents the highest value for money achieved, of course in regards to the process and human limitation.

5.1. *Life Cycle Cost Inspector Case Study – The Whole Building Assessment*

Within the LCCI software interfere there two main types of buildings assessment. The fist type focuses on the building itself. It breaks down the whole building into separate components (components division is based on Building Cost Information Service of RICS [5]) and each component is subsequently researched. Based on the material and quality characteristics the Operational Expenditures are predicted. An example of a project break down is summarized in Table 2 [6].

Table 2. Building’s components indicating operational costs

Component	Capital Expenditure (EUR)	LCC Cycle (Yrs)	Total Cost of Replacement (65 years) (EUR)
Substructure	823,302 €	70	0 €
Frame	4,838,803 €	70	0 €
Upper floors	1,756,362 €	70	0 €
Roofs	664,938 €	25	1,488,924 €
Stairs	2,073,773 €	30	357,013 €
External walls	1,676,847 €	30	1,198,653 €
Windows and external doors	2,485,059 €	30	3,552,768 €
Internal walls and partitions	379,847 €	20	1,013,470 €
Wall finishes	413,317 €	10	2,185,142 €
Floor finishes	413,317 €	10	2,052,185 €
Ceiling finish	413,317 €	15	721,743 €
Sanitary appliances	119,015 €	10	666,010 €
Water installations	153,018 €	15	533,308 €
Space heating and air treatment	1,645,553 €	10	5,558,375 €
Ventilating system	3,091,121 €	10	23,063,999 €
Electrical installation	4,856,285 €	10	36,234,539 €

Total	25,803,873 €	78,626,130 €

The Total Costs of Replacement (the last column in Table 2) is estimated according a life span of each component, incudes preliminaries, risk allowance, maintenance and renewal costs. Further, the operational expenditures are discounted in order to reflect the time value of money – that is summarized in the Table 3.

Table 3. Overall cost of replacements

Type of Cost	Total
Cost of replacement - annual (65 years)	3,049,031 €
Cost of replacement - total (65 years)	78,626,130 €
Discounted cost of replacement - annual (65 years)	17,483 €
Discounted cost of replacement - total (65 years)	5,953,008 €

A specific discount rate, which is estimated for each new building analysis according the specific risks, inflation and low-risk investments, allows for the difference between present and future money.

5.2. *Life Cycle Cost Inspector Case Study – Options for Heating and Cooling*

To demonstrate the second assessment process of the LCCI – the component analysis - it is necessary to select the components, which will be researched. For purpose of this study a comparison of induction units (cooling beams) and more traditional fan coils has been used.

The option A is defined as a technical solution where the distribution of fresh air and temperature treatment is achieved by induction units, which are usually placed visibly under the ceilings, and are expected to last for 20 years with minimum operational expenses [6].

Induction units are significant by their cost savings during the whole life cycle. First of all, induction units provide energy savings due to lower (or higher) needed temperature as in standard heating and cooling systems. Moreover, maintenance costs are reduced due to omitting of all moving parts, which are present in the fan-coil systems. The only maintenance requires annual cleaning – dust wiping and vacuum cleaning, but absence of moving components like fans and absence of filters decrease in general danger of potential failures and additional operational expenses.

As an Alternative A to the Induction Units the Four-pipe Fan Coil system has been chosen. It is expected that the four-pipe Fan Coil system is usually replaced every 15 years, which is 5 years less than the lifespan of the induction units. Four-pipe Fan coil contain: filter, fan and two coils (heating and cooling coil), so that there are four connection pipes. Hot water or chilled water is always available. The system is able to instantly switch from the heating mode to the cooling mode, or vice versa, and can provide heating to some rooms while simultaneously providing cooling to other rooms. Because of high flexibility the fan-coil system create noticeable incentive for implementation.

The Four-pipe Fan Coil system requires substantial expenses in terms of maintenance and operation. It is expected that fans will be replaced every three years. In addition to that filter cleaning and minor replacement must be performed every six months.

Therefore, the Four-Pipe Fan Coil system will accumulate significantly more operational expenditures than induction units. The total overview is depicted in Fig. 1.

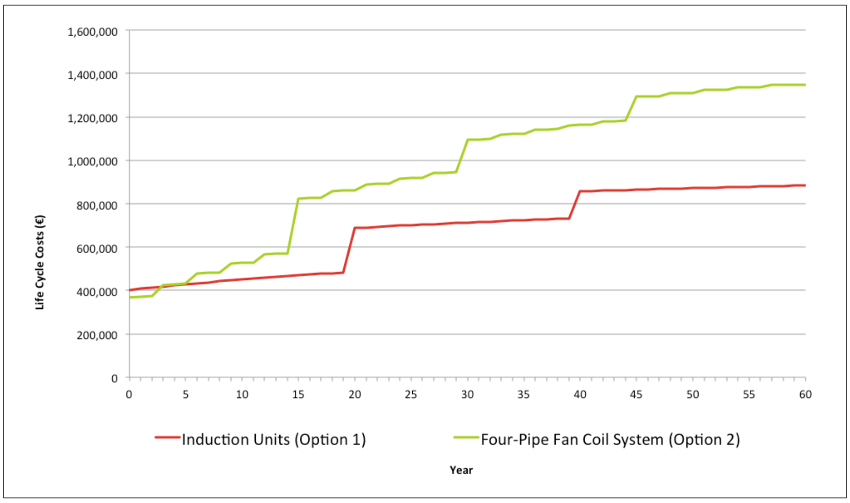

Figure 1. Component analysis - Induction Units vs. Fan-coil Units

Data specifics of the component analysis are visible in Table 4, where both options reflect their performance in 25 and 60 years and in simple and discounted terms.

Table 4. Summary of the component analysis – Induction Units vs. Fan-coil Units

Type of Cost	Induction Units (Option 1)	Four-Pipe Fan Coils (Option 2)
Initial Cost	401,517 €	368,157 €
Life Cycle Cost (25 years)	951,483 €	1,245,408 €
Life Cycle Cost (25 years) - discounted (25 yrs)	701,172 €	918,073 €
Net Savings (25 yrs)	293,926 €	0 €
Net Savings (25 years) - discounted	216,901 €	0 €
Life Cycle Cost (60 years)	1,554,890 €	2,680,392 €
Life Cycle Cost (60 years)	882,546 €	1,349,265 €
Net Savings (60 yrs)	1,125,502 €	0 €
Net Savings (60 years) - discounted	466,719 €	0 €

The induction units have marginally higher initial cost than the four-pipe fan coil system. However, after three years of operation this difference is reduced due to lower maintenance cost of induction units. Since “Year 3” the difference is steadily growing and the four-pipe fan coil system is becoming highly uneconomical. Longer replacement intervals, lower operational costs and lower probability of damages are creating incentives for procuring induction units instead of the four-pipe fan coil system option.

Now, let’s assume that the principal selection criterion is the lowest cost – in this case it would be the initial cost (Table 4). Based on a simple comparison, the Option 1 (Fan-coil units) would be chosen over the Option 2 (Induction units). But it is obvious that the operational savings of the preferred Option 1 would be 466,719 € (Net Savings (60 years) – discounted), and that indicates additional expenses for operation, which could have been avoided by selecting the Option 1 – Induction Units.

6. Conclusion

The true purpose of the Life Cycle Cost Inspector’s methodology is creating a simple tool, which promotes straightforward assessment of different investment options in regard to the capital and operational cost. Even though the software processes are rather computational; the outcome of each assessment must be presented with a clear narrative summarizing all qualitative and quantitative findings. Only based on that, the preferable option can be selected and thus the value for money achieved.

Based on our results the lower initial capital cost does not ultimately lead to the more effective investment. In the context of the whole life cycle, the sustainable design positively affect the operational costs and thus decreasing the overall burden on the public sector budget.

Without a clear evaluation paradigm, which defines the preference of the value for money rather than the initial cost, the public sector representatives will always incline to the philosophy of selection the lowest cost, which promotes “safer” and easier procurement path but never truly reflects the operational phase of the asset.

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Substantiation of Decision Making Processes in Construction Management and Real Estate Development

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Abstract

Theories of how to support crucial decisions by optimizing weighted variables and aspects are widely known. The mathematical ground is well prepared and in no way distinguishable from hard-fact optimization. However, the transformation of soft factors into solid contributions to a virtual target function is mainly left to intuition. The fuzzy approach proposed by Zadeh during the seventies has turned out to be impractical and is recently more or less being ignored. Yet, methods of weighting soft factors based on different score systems, in fact directly derived from the Zadeh approach, are gaining ground. They are used e.g. in deciding for the complexity of planning tasks in Construction Management based on the HOAI as well as in analysis of procurement criteria, the definition of factors of success or in generally investigating network structures by means of cross-impact-analysis.
However, optimizing by the application of differential calculus and integrating difficult matters by simply translating advantages and disadvantages into virtual costs and profit, furthermore, the assignment of scores by more or less arbitrarily chosen curves seems a very inaccurate approach to proper judgement. Finally, so far resulting soft optima allow for no explicit evaluation and decision-making. Yet, this approach allows for analyzing the sensitivity of such a decision towards specific aspects and variables by backward modification, which is investigated in this article.
It turns out that backward analysis provides a much better access to the reasons and arguments for or against a specific decision and thus allows for well-reasoned judgement. In particular, the scope of proper application is demonstrated with BIM-Modeling based on multi-valued logics, including the meta-level modelling of control processes in Construction Management and Real Estate Development.

Keywords: Decision-Making; Control Processes; Procurement; Factors Of Success; Multi-Valued-BIM-Modeling.

1. Introduction

Decision-making has always been a matter of instinct based on experience and expertise of the responsible person [e.g. 12]. As all risk management issues finally rely on the supporting knowledge and estimation [23, 36, 39, 42, 43] and the impact of wrongly elaborated decisions is tremendous, efforts have been undertaken to place decision-making processes on more substantiated grounds [2, 3, 11] to ensure safe results [13, 17] as well as to protect the decision maker. This leads to the classical procedures of optimizing multivariable systems with respect to one target function in order to have at least some mathematical support for optimized decisions.

Standardized approaches are given by e.g. methods of multidimensional differential geometry, where for discrete situations well-known algorithms from simplex via transport algorithms and assignment algorithms of all sorts [9, 18] are available. They have in common to take into account a well-defined set of variables, subjected to a set of conditions and providing a singular or multiple optimal configuration vector with respect to an again well-defined target function [19, 27]. In previous times these algorithms were carefully engineered in order to save computing time and space of memory as the number of variables or conditions tend to become huge. Today, well-designed algorithms are available and computing power is in most cases no more a seriously restricting factor.

Thus, the question arises why still unsupported decisions are made and a significant number of such decisions is known to fail. This article intends to point out the real limiting factors which are located more in the deciders mind than in the methods applied and to propose an approach to additionally model and allow for judging these.

2. The Optimization Problem

2.1. *General Formulation*

Generally, a set of variables $\{x_i \mid i \in \mathbb{N}, i \leq n\}$ forms the basis for the description of all relevant criteria, which are to be obtained where the scalar target-function $G(x_i)$ is at maximum. Thus, a vector $x = (x_i)$ with dimension n in the space of states points to a general state. The vector $\bar{x}$ represents the optimum state if $G(\bar{x}) = Max$, as described e.g. in [1, 4, 8, 20].

The components can be of any kind, continuous like costs of crews, rents or performance parameters as well as discrete representing numbers of devices or workers to be used, numbers of lanes of a road or even be two-valued like a project to be accepted or rejected as a Boolean decision. There is even no need to construct these components to be comparable, as only the overall maximum of $G(x)$ is to be obtained.

The target-function needs to be of scalar type as only one criterion can be optimized which often causes conflicts since e.g. cost as well as duration need to be minimized. However, in this case time needs to be translated into cost resulting in a target-function representing not necessarily real cost but virtual cost, i.e. something unwanted which is to be minimized. The dependence on $\bar{x}$ can be linear or nonlinear with the only consequence of different approaches to be applied for calculation. Even the existence of poles only complicates the obtaining procedures but is no principal hindrance. Yet, the interpretation of the result might become more difficult.

Finally, a set of conditions might be defined restricting the space of solutions in some way. These are generally formulated as $F_r(x) = 0 \mid r \in \mathbb{N}$ or possibly as $F_r(x) \leq 0 \mid r \in \mathbb{N}$. The latter definition allows for no differential approach as it leads to discontinuous equations but reflects reality much better.

Depending on the structure of these equations, a multitude of methods and algorithms is available for strict or at least approximate solutions. A typical representative would be the simplex family, which allows for all linear sets of equations including inequations as conditions. A large set of problems can furthermore approximately be handled by linearization and then being subjected to simplex tableaus [7, 8].

2.2. *The Transformation Problem*

All required information needs to be formulated as explicit variables. This is not only needed for entering the criteria to the restrictions and to the target-function, but also for final interpretation purposes. Even very diffusive criteria must be returned as components of the resulting vector representing a clearly defined dimension in the space of states.

Therefore, even very fuzzy variables like the degree of traffic jam in a road network optimizing problem needs to be transformed to a value e.g. of virtual costs. Some can be translated or calculated as explicit cost like the lacking profit by vacancy of property but also the visual impact of vacant stores in a shopping center on the operative adjacent stores needs to be taken into account [45, 46]. Likewise, missing a target date might have financial consequences given by the contract as punitive damages but in addition to this, the damage on the reliability of the respective company needs to be valued and taken in [14, 21, 31, 38, 48, 49].

Such consideration turns out to be difficult and crucial but mathematical methods can only be applied if absolutely every aspect has been translated to meaningful values. This is in no way a mathematical problem but merely a typical engineer’s task. Due to the lack of precision, explicit approaches are widely avoided and replaced by opinions, gut feeling and unfounded decisions.

2.3. *The Optimization Problem*

As long as the mathematical problem can be solved, a number of well-defined optima $\bar{x}_j$ can be calculated. The actual meaning of the given result is however to be interpreted by the engineer. This excludes probably meaningless just mathematical solutions e.g. complex zeroes or negative numbers etc. Yet even useful zeroes need to be judged carefully regarding their strength [34, 40, 41]. In many cases, flat optima are obtained indicating a very weak dependency of the target-function in close proximity of the optimum. Thus, a large deviation from the resulting optimal vector means no significant loss of optimality leaving the carefully calculated result rather fuzzy.

On the other hand, optimal vectors may represent a peak of the target-function allowing for no deviation without strong losses on optimality. Under such circumstances, considering several peak optima with different characteristics a second choice with an even lower value of the target function may appear more convenient as the respective variables cannot be kept safely on the required sharp value on the peak.

On this background, the mathematical procedures of optimization turn out to be the least problem; judging resulting peaks in terms of sharpness and considering the characteristics of the underlying respective variable regarding determination and controllability is the greater challenge.

Thus, the second derivative of the target-function at the zero not only provides the sign indicating a maximum or a minimum but also by its value informs about the averaged difference of loss of the target-function between sitting one and minus one units away from the zero. This is given by the specificity S of the optimum

$$S^{-}(\bar{x})\Big|_{i-\varepsilon} = \frac{\partial}{\partial x_i} G(\bar{x}-\varepsilon) \qquad S^{+}(\bar{x})\Big|_{i+\varepsilon} = \frac{\partial}{\partial x_i} G(\bar{x}+\varepsilon) \tag{1}$$

$$S(\bar{x})\Big|_i = \frac{\partial^2}{\partial x_i^2} G(\bar{x}) = \lim_{\varepsilon\to 0} \frac{S^{-}(\bar{x})\Big|_{i-\varepsilon} - S^{+}(\bar{x})\Big|_{i+\varepsilon}}{2\varepsilon} \text{ (Average of } S^{-} \text{ and } S^{+}\text{)} \tag{2}$$

Making use of this, the scales of the single components x_i are no longer insignificant but need to be comparable since an optimum wants to be judged with respect to all variables.

3. Fuzzy approach

3.1. *Fuzzy space of states*

In particular, as the dependency of a derived optimum needs to be analyzed with respect to a specific variable the quality of the definition and determination of each variable comes into play. Some calculable variables are well determined and therefore cause no severe problems. Yet variables given by feelings, image, mood or otherwise being only subjectively determinable become critical as well as situations where well-defined variables are affecting the target-function only in a virtual manner. In general, the problem of transforming fuzzy variables into well-determined values is required.

During the sixties L. Zadeh introduced Fuzzy Logic dealing with the problem of many decisions being not a clear yes or no but to some degree both of the two-valued space [32, 33, 29]. This concept is not only valid for logical decisions but also for the transformation of fuzzy information into determined variables and *vice versa*. The proposed concept approaches classical logic calculus as the values become sharp and can therefore be considered as an extension of the classical understanding.

A function $x_i = H(y_i)$ simply is intended to map the undetermined variable y_i to the well-determined variable x_i. According to Zadeh, *H* contains the agglomerated knowledge of experts and therefore is as good as possible a means to assign each value of x_i a “degree of truth”, ranging from 0 to 1. Thus, more than a single strict assignment is available. On those functions H Boolean operations like AND, OR and NOT can be applied as the intersection, the union or the complement of the “truth”-values of the respective input in order to form more complex representations of specific variables.

$$\begin{gathered} H_{1\&\&2}(y) = H_1(y)\ \&\&\ H_2(y) = \int_0^\infty Max\big(H_1(y), H_2(y)\big)dy \\ H_{1||2}(y) = H_1(y)\ ||\ H_2(y) = \int_0^\infty Min\big(H_1(y), H_2(y)\big)dy \qquad \overline{H}(y) = \int_0^\infty 1 - H(y)dy \end{gathered} \tag{3}$$

The resulting set is a function of which the center of gravity is interpreted as the determined result.

$$y_{def}(x) = \int_0^\infty yH(y)dy \Big/ \int_0^\infty H(y)dy \tag{4}$$

This approach has been tried a lot but went finally more or less into oblivion, probably because the assumed consensus of experts forming $x_i = H(y_i)$ as a valid transformation is doubted for good reasons.

3.2. *Exemplary Usage*

However, the same is made use of, without mentioning it, in a wide range of well-known scientific approaches, where the particular transformation is commonly agreed on.

3.2.1. Questionnaires

Questionnaires are commonly used to explore markets by summarizing the personal opinions of a large universe of participants [e.g. 27]. Hence, the singular opinions, which are of no scientific weight, become a well-based description of the market if thoroughly chosen and evaluated based on a sufficiently large number of respondents. On this background even personal preferences can be asked and the results be transferred into strongly defined values. Basically questions refer to score systems e.g. a scale from “Like” to “Dislike” ranging from -5 to 5 scores which simply transforms a very fuzzy information to a well-defined value given by the center of gravity, i.e. the mean values. The linear or even nonlinear assignment of scores defines the transformation of the fuzzy "liking" to the result. In situations that are more complex several bits of fuzzy information are combined by the utilization of the respective Boolean operations.

3.2.2. HOAI

The definition of the difficulty of a design task for a planner within the HOAI is given as the assignment of the task to one out of five groups and if required to a similar score system allowing to measure the precise level of difficulty worth the respective remuneration [45, 47]. Even if more complex operations are not implemented here this system works the classical Fuzzy structure as introduced before. In particular, not so much the linearity but the granularity of the assignment is simply agreed on and not called into question.

3.2.3. Factors of Success

Investigating factors of success and their impact on success is also not really well defined. Factors need to be identified which have a strong and direct impact on success itself but can be measured and controlled during the runtime of a project while success itself can only be determined at the end of the project [24, 37, 44, 46, 48, 49]. Transfer-functions from the respective factors to the target-function of success are in general not explicitly given. However, success is controlled by making strict plans and the attempts to follow these as the only means to ensure success. Thus, implicit transfer-functions are assumed but never measured or checked out.

3.2.4. Procurement Criteria

As procurement criteria, the final price is only one issue to be considered. Additional aspects to be necessarily taken into account are clearly not directly measurable [10, 19, 22, 35]. There would be of importance e.g. experience of the project team, price difference to the best, size of company, experience with comparable projects, presence on the market, experience with customers, locality of company, history of company, contribution of particular personalities, degree of offered subcontracting, nationality, legal basis, size of market etc. Since these criteria are not available for measurement and additionally the modelled impact on the final decision is not of a mathematical type, a transformation-function is required. In some cases, this might be linear but mostly it will be strongly nonlinear. E.g. judging the wanted presence on markets neither none nor a full yes is wanted, but probably a carefully selected degree. Thus, a transfer-function might show a strong peak at some value in between. All criteria need to be subjected to transfer-functions and entered to a score system, which is weighted against the best price in order to pick the optimal offer.

3.2.5. Cross-Impact-Analysis

In Cross-Impact-Analysis the future situation of a network is investigated where the influence of nodes on other nodes is known [5, 6, 15, 16, 25, 28, 30]. In some – more physical - cases, impact factors are given by transfer-probabilities and are therefore accessible via respective measurements. Where networks are used to model social interactions e.g. representing participants of a project or just political or economic issues influencing each other the strength of interaction can no more be measured but must be estimated. Vester [26] makes use of a linear scoring system ranging from none to strong influence in three steps. In describing the particular meaning of a given score value nonlinear influence is integrated to the model. Finally scores are summarized i.e. ANDed or multiplied i.e. ORed for higher order evaluation of the network behavior.

3.2.6. Building Information Model

In a Building Information Model (BIM) every aspect of a building including its interaction with other elements is modelled and expected to automatically detect possible clashes. Mainly physical construction elements and their interfaces can well be described accordingly while operational aspects, e.g. the construction processes and the executing units, cannot be included directly due to the work contract type of interference. In order to gain reliable information about the operational behavior of a specific project network, fuzzy interaction given by coordination capabilities needs to be introduced to the model – making use of appropriate transfer functions. Due to the necessarily general character of these, only general parameters describing the operability of the project team will be returned [46] as the effectivity of the respective control processes.

4. Backward impact analysis

4.1. *Fuzzy space of states*

The need of integrating freely chosen transfer-functions for unmeasurable variables cannot be helped. However, they need to be defined carefully in advance. A much stronger test for their appropriateness would be to track them back from the location of the identified optimum by calculating the second derivative of the target-function, i.e. the specificity.

If the respective variable was measured in some existing units and just the transfer is being made arbitrarily combinations of triangle-functions are chosen in many cases to reflect multilinear interdependencies due to the lack of a better description. If additionally the unit of the variable is unavailable, at least verbal descriptions are existing, mapping expressions like "strongly", "indifferent", "most indifferent" "not at all" etc. to an amount of scores which are can be processed further [32, 33]. In any case, a well-defined set of possible input options is assumedly well described as the input originated once from it. This step of generating estimations is in general made in advance with no knowledge of the possible consequences of a particular selection. Proceeding along this sequence is important since otherwise decisions will be adapted to an expected or preferred result of the investigation and neutrality is no more guaranteed. Yet, the result can be tracked backward and provide a precise interpretation of what the actual meaning of a selection of a specific variable with respect to the optimal situation would be.

The second derivative of the target-function i.e. the specificity with respect to a imprecisely measured variable yields the exact description of the state if the optimum is deviated by a certain degree in the words originally defined for the variable in question and is therefore interpretable on this level. The left-sided first derivative yields the description of the lower selection together with the loss of optimality S^- while the right-sided is responsible for the higher selection S^+. The second derivative allows judging the overall sharpness of the peak as the sign-adapted averaged loss of optimality between one unit to the left and one to the right of the optimum.

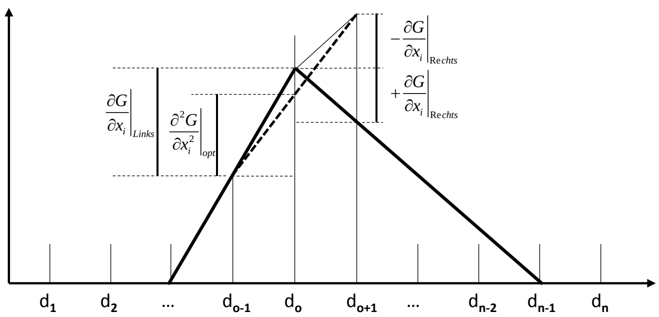

Fig.1. Interpretation of specificity at the location of an optimum.

Since each variable remains to be treated as a unique dimension to the problem, multi-linearity is only to be expected as a transfer-function introduced in advance being formed by a set of not matching triangle-functions as the result of several disagreeing experts. However, in this case the more complex transfer-function is well known and can be interpreted respectively, if not differentially the possibly by using discrete differences. All transformations to finally construct the target-function are unaffected as dimensions are being kept separately and the derivative with respect to x_i can be analyzed independently.

5. Conclusion

The proposed approach is expected to improve the solidity of decision-making by explicit judgement of the specificity role the respective variables play. It seems to be unavoidable to introduce soft variables, which cannot be calculated explicitly but need to be described by the use of verbal explanations. These need to be translated to describe their influence on the target-function, which is also done via soft transfer-functions. In former times, such procedures have been executed and the impact of the fuzziness was ignored relying on the assumption of a properly determined description.

Since this cannot be expected to be accurate, in general the reverse approach is required in order to prove the significance not only of the variable in general but in particular on the background of the specifically elaborated optimum. Thus, the relevance of the calculated optimum can be judged based on the originally introduced wording of the respective descriptions. From these procedures, some improvement on the stability and reasonability of decisions can be expected.

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Decision Making in Reconstruction Phase after War

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Abstract

Most segments of Syrian society have been affected by the results of the current war, and perhaps the most important and serious result is the unbalanced demographic distribution of the population. Syria is concerned about how to put the integral strategy for the process of reconstruction of the totally and partly destroyed areas. This strategy will be realized by putting plans for the production of an integrated map, which includes an initial perception of all communities within small or medium residential cities, with all commercial, industrial, agricultural and tourist events, rather than regulatory and non-regulatory areas which currently have become destroyed and unfit for restoration and housing.
In the stage of the housing plan, researches were done in order to assess the reality of the construction of buildings in Syria, compared with the concepts of the industrial building system (IBS), to evaluate the factors affecting this industry, and proposals of applying it in the reconstruction stage. the results were as following: cast-in-place concrete in the case of the reinforced walls got 13.1%, while in the case of the framework structure it was 34%, and templates tunneling 64%, composite order (pre-cast and Cast-in-place concrete) 61%, composite order (concrete and metallic) 67.25%, and the pre-cast concrete from 82% up to 86%. This research has also arranged the priority use of technical systems in construction in Syria using the method of AHP (Analytic Hierarchy Process), the advanced technology system (pre-cast concrete) was in the first place with 39.4%, with knowledge that it faces significant challenges in spite of its inevitability as a strategic decision in finding solutions to the problems of housing and reconstruction.

Keywords: Construction industry; decision making; industrial building system IBS; modern building systems; war

1. Introduction

Construction industry forms an evolutional orientation for construction sector, which is considered one of the important economic sectors, in terms of its role in the formation of fixed capital and gross national product, and the magnitude of its employees [1]. The world has seen a significant expansion in the field of building and construction in the aspects of technology and productivity, but this industry is currently facing unprecedented developmental pressures in our country as a result of the lack of resources and the rising prices of raw material and the instability of environmental factors surrounding it. This is what prompts us to think about the system to frame the industry in order to evaluate it and make advancement towards the best, in order to achieve the requirements of sustainable development. The advancement of the construction sector towards the foundations of the construction industry requires the use of developed technological and administrative systems, compatible and in harmony with the architectural and constructional and technical systems for buildings so that they can get the product within sophisticated modern standards. Therefore, and due to the magnitude of the housing crisis and the deficit in securing the required modules, speed factor become an urgent need [2].

1.1. Research methodology:

- Review of previous studies about the construction industry and modern techniques used.
- Assessment of the reality of the Syrian construction experience and measurement of the *IBS* degree for the Syrian construction projects.

- Using a questionnaire to find out the most important factors affecting the construction industry and the extent of the current application and the importance of development in the future and analyzing the results of the questionnaire using the *SPSS* program.
- Determination of the priority to choose one of the technical systems used for construction in Syria using the Expert Choice program.

1.2. Benefits of adopting IBS:

The questionnaire and field survey showed that in despite the promotion of benefits in *IBS* adoption, the industry stakeholders and contractors are still sceptical about the *IBS* usage since issues such as technical difficulties, enormous capital cost, design conflicts and skill shortages during the construction phase represent? The barriers. Accordingly, in addressing a knowledge gap in the construction level, this paper has tried to explain the benefits of using *IBS* components. Numerous benefits of adopting *IBS* had been reported by academicians around the world and becoming the driving forces to the construction industry players in deciding whether to use *IBS* or not [3]. The benefits of *IBS* adoption are summarized in Table 1 as follows:

Table 1. Summary of IBS benefits.

Benefits	Explanation
Cost and financial	IBS offers cost saving through: - Earlier completion time (Kamar et al.2011; Pan et al., 2007). Repetitive use of system formwork made of steel, aluminium, etc. (Thanoon et al., 2003; Besharah et al., 2015). - Less wastage (Idrus et al., 2008). - Reducing site infrastructure and overhead (Kamar et al., 2011). - Increased certainty less risk (Pan et al., 2007.
Reducing labor	The using of foreign labour (Jabar, 2013). The using of IBS component, which is manufactured in centralized factory, automatically will reduce labour requirements at construction site (CIDB, 2010).
Better quality	Better quality products can be produced with the adoption of IBS as it uses good quality components and involved numerous expertise throughout the process starting with manufacturing, installer, engineers, contractors and others (Kamar et al., 2011; Thanoon et al., (2003).
Health and safety measures	IBS application will improve site safety by providing cleaner and tidier site environment (Pan et al., 2007; Rahman & Omar, 2006) as the site activities become minimum (Besharah., 2015).
Flexibility	IBS allows flexibility in architectural design, in order to minimize uniformity of repetitive facades. Simultaneously, the flexibility of different system used in IBS construction process produced own unique prefabrication method (Thanoon et al., 2003).
Waste minimization	All IBS components are manufactured from the factory, resulted in less wastage (Kamar et al., 2011).
Improving productivity	Productivity (CIDB, 2010; Kadir et al., 2006). At the same time it enhances productivity by removing difficult operation off-site and less site disruption (Arif & Egbu, 2010).

Source (author and Izatul laili Jabar et al, 2013)

1.3. Previous studies

Defined [8] *IBS* as the components' manufacturing, assembling, transporting, and placement construction using minimum additional work possible inside or outside the site. While the Construction Industry Development Board (CIDB) in Malaysia defined IBS as a building system where components being manufactured in the factory or off-site, then developed and assembled into a structure with a minimum of extra work at the site [10]. [14] Defined the IBS as an integrated manufacturing and building process, organized and planned well to achieve efficiency in the management, setup and control of resources used and support the activities and results using sophisticated components. There are different classifications of *IBS* according to [4] depends on: materials, processes and systems. It is important to develop a clear vision for different types of construction systems and modern techniques used that contribute to get the IBS and are an integral part of it. Generally, there are four types of building regulations in accordance with the Badir-Razali Building System Classification which are: traditional building systems, cast in place, pre-made, and composite [15]. Each of the construction systems is represented in accordance to their own construction methodology, and its advantages in additions in construction technology, and the engineering and functional composition [5] as shown in Figure 1. The different templates systems offer a wide range of concrete construction solutions that can be selected to suit the required development needs [16].

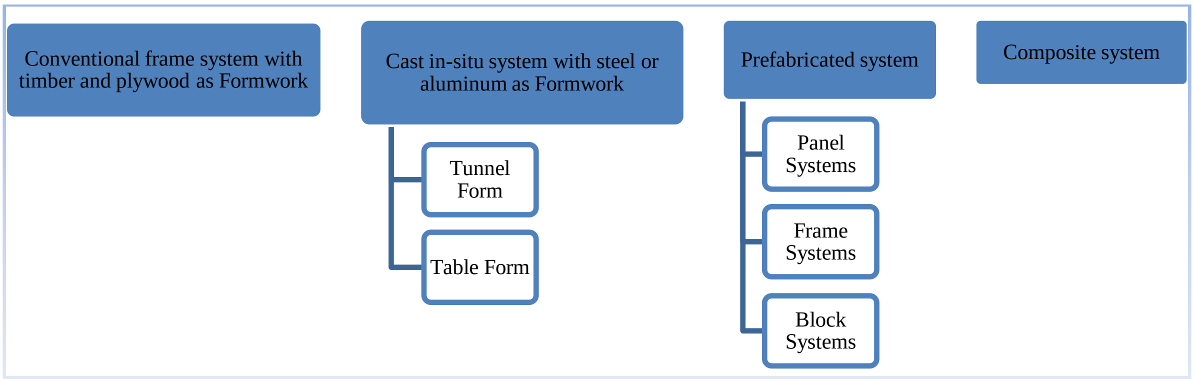

Fig1. Types of Building Systems (Source: author with using [5])

2. Results and discussion

Assessment of the level of *IBS* for the executive solutions patterns used for buildings in Syria:

2.1. Description of implementation modalities in Syria:

The dominant pattern of systems implemented in Syria is the using of templates of woody tambourines in the implementation of building structures (columns and walls and slabs cast in place), and there are less cases of using templates of small panels, or large panels of slabs and walls, and some cases of the use of tables templates, and tunnelling templates that are used for walls and ceilings. The construction experience in Syria refers to the use of pre-cast for the construction of residential suburbs, also the use of composite implement (cast-in-place and pre-cast) in some partial solutions in construction. A review of the Syrian experience in the evaluation of some performance indicators (time, quality, and cost) refers to a low level of these indicators [17]. The proposed system to assess the level of the construction industry in Syria *IBS* is a systematic and structured evaluation system; it can be used to measure the amount of using the *IBS* appropriately. Among the criteria adopted to measure the IBS is the measurement of the Construction Industry Development Board in Malaysia (CIDB) which is an important criteria with clear scientific methodology that supports our adoption of this approach for measuring the construction industry [10].

2.2. *Principles applied to evaluate the construction industry (PRINCIPLES OF IBS SCORE):*

The system of calculation of the *IBS* points focuses on several features of the construction specifications, such as using pre-cast components, production of components off-site, the use of standardized components, and the repetition, in addition to the design using the concept of consistent units. The method of determining *IBS* points is designed to be simple but scientific and effective. Points are awarded on the basis of *IBS* transactions of the components of structure and walls, and taking into account the contribution of repetition proportion in the design in total points. It should be noted that the maximum points for *IBS* of the building is 100 points are calculated according to the equation (1), the formula according to [10], *IBS* calculation formula:

$$IBS = 50\sum\left[\frac{Qs}{Qst}Fs\right] + 20\sum\left[\frac{Qw}{Qwt}Fw\right] + S \tag{1}$$

Qs: Construction area of a structural system.
Qst: Total construction area of building.
Fs: *IBS* Factor for structural system.
Qw: Length of a wall system.
Qwt: Total wall length.
Fw: *IBS* Factor for wall system.
S: *IBS* Score for other simplified construction solutions, as build ability and repetition.

2.3. Calculation of IBS degree for patterns of structural and executive solutions used for buildings in Syria:

The *IBS* degree for patterns of structural and executive solutions used for buildings in Syria was calculated based on the projections and building's data, and using the equation 1. Note from the fig 2 the high points of the *IBS* for pre-cast concrete system in Syria (82% - 86%), and this shows the importance of this system and the large role in the technological and production development required in Syria. Where it offers many advantages in terms of the production of a large number of units and the reduction in cost and time and improves the quality of the work [10]. The composite system comes in second place, it has a limited use in the shelters housing (pre-cast concrete and metal) increased by 67.25%, this shows the important role of this system in limiting the effort at the site and reducing the time necessary to accomplish the task to a large extent. In third place, is the cast-in-place concrete system with tunnel templates by 64%. In fourth place was the composite system (pre-cast concrete and cast- in- place) with 61%. Followed by the cast-in-place concrete system in the case of a framework structure with 34%, and it is noted that this system existing in many of the Syrian buildings and must work to improve its points in the future. In last place came the cast-in-place concrete system in the case of reinforced walls with 13.1% and this low rate is due to the absence of the use of technology and the need for a lot of effort at the site. It is therefore concluded that the use of a high proportion of the components of *IBS* in order to obtain the building industry needs to move towards prefabrication and other advanced technologies. Units manufactured in Japan accounted for about 20% until the year 2000 [18]. While in Malaysia up to 10% of the total overall housing units [19]. The manufacturing use in Syria is low, due to the lack of local knowledge in many aspects, especially its application, and the prefabrication factories are rare, despite the fact that plans for reconstruction depend on rapid construction systems and turnkey construction.

2.4. Identification and analysis of factors affecting the construction industry in Syria:

There are many important factors affecting the construction industry, and due to the complexity of these factors, their importance must be identified and determine according to Syrian reality and meet the needs of reconstruction, so it was resorting to the questionnaire, which is good means for the collection of field data and is characterized by the possibility of collecting information from multiple sources of the study sample and analysing it to reach specific results.

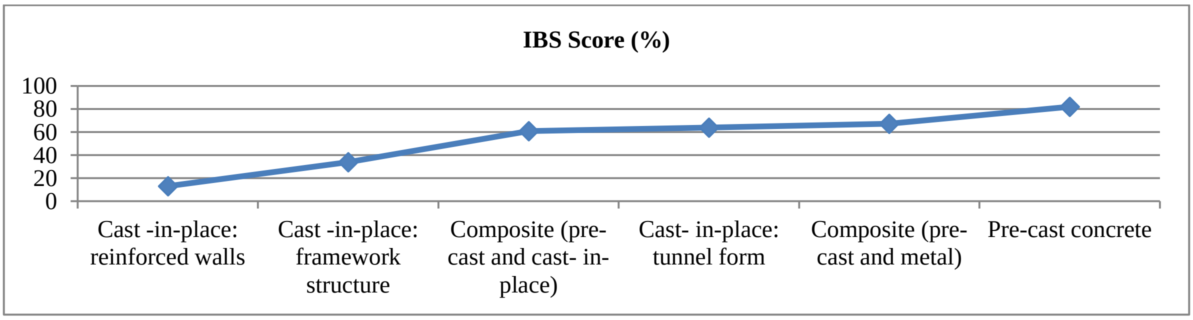

Figure 8: *IBS* Scores according to building system. Source: Authors' own calculation, 2015.

2.5. The design of questionnaire:

It has reviewed several previous international research studies, including [12], [20], [21], which looked at evaluating the performance of the construction industry, and found a number of important factors affecting this industry. The questionnaire was distributed to 100 establishments operating in the field of engineering; the experience of each individual in the sample is ten years in minimum and up to 40 years. The study sample ended with 51 acceptable responses which have been analyzed.

2.6. Statistical methods used in the study:

To test the availability of internal consistency and coherence between the answers, were calculated the Cronbach's alpha coefficient (Alpha- cronbach) as a reliability coefficient was calculated, where the result coherence coefficient for the current application part is 96.1%. And for the part of the future importance is 98.4%, knowing that the acceptable value of Cronbach's alpha coefficient is (60%), also we observed high truth values of both parts so can depend on the study sample answers and then data analysis, to analyze the data from the questionnaire, we used the SPSS 19 program. Analysis shows from the economic point a significant decline to adjust the construction time, and this indicates a clear deviation in controlling the duration of the projects. But from the human resource management point of view, we note a high repetition of answers in the low category for each of the variables security and safety of workers and training and education, which refers to the urgent need to achieve safety requirements in the projects and provide the necessary rehabilitation courses. In terms of infrastructure, we note the low application for availability of factories and support mechanisms for the construction industry, and provide a means of specialist technological transport, which leads us to work on the supply, and importing logistics and technology suitable to the reconstruction plan in Syria. We noted a reduction of all the environmental variables indicating the omission of the environmental aspect in the Syrian construction projects. According to the regulatory and streptococcus management side, note the heavy reliance on the lowest price in the bidding management, high government bureaucracy which constitutes a major obstacle for the success of the Syrian construction projects. Administratively, we noted the decline of the availability of managerial skills, as well as reduced government intervention through the enactment of laws and regulations, and the follow-up of existing projects, and this is what refers to the importance of developing the administrative enactment of laws adequate with the reconstruction plans.

2.7. Steps to implement the AHP:

For decision-making about the technology that must be followed using one of the decision-making tools, a method of hierarchical analysis of the *AHP*. The process of the *AHP* include three basic steps: the first step is to build a model of hierarchical analysis, which consists of the primary goal, alternatives and the main and sub-criteria, the second step is to demand from decision makers to individually express their opinions regarding the relative importance of the criteria and preferences between alternatives using paired comparisons, the third step is to prioritize the decision. After preparing the overall shape of the model, and introduction of the preference values to the program (expert choice) for comparison of the alternatives (technical systems) for standards, was obtained the result of the final paired comparisons of alternatives according to figure 3. Shown in figure 3 that technical system which received the highest importance, among other technical systems is the technology advanced prefabrication system and that had the winning percentage of 39.4%, and the researcher returned it to the extent of the actual importance of the advanced prefabrication technology, which stems not only from its large contribution in the rapid construction, but also in its ability to fill a large proportion of the housing needs of the Syrian citizen especially in light of the risks to the destruction of Syria and the pressures of development and the great need of reconstruction. The technical composite system (cast-in-place, pre-cast) came second with 21.8%; followed in third place by a low difference developed technology the cast-in-place system gaining 20.8%.

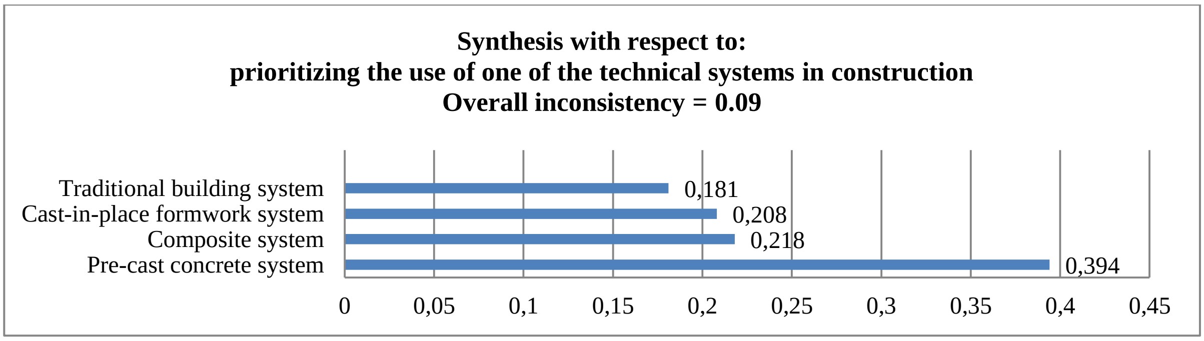

Figure 9: order of technical building systems after a paired comparisons using expert choice. Source: Authors' illustration, 2015.

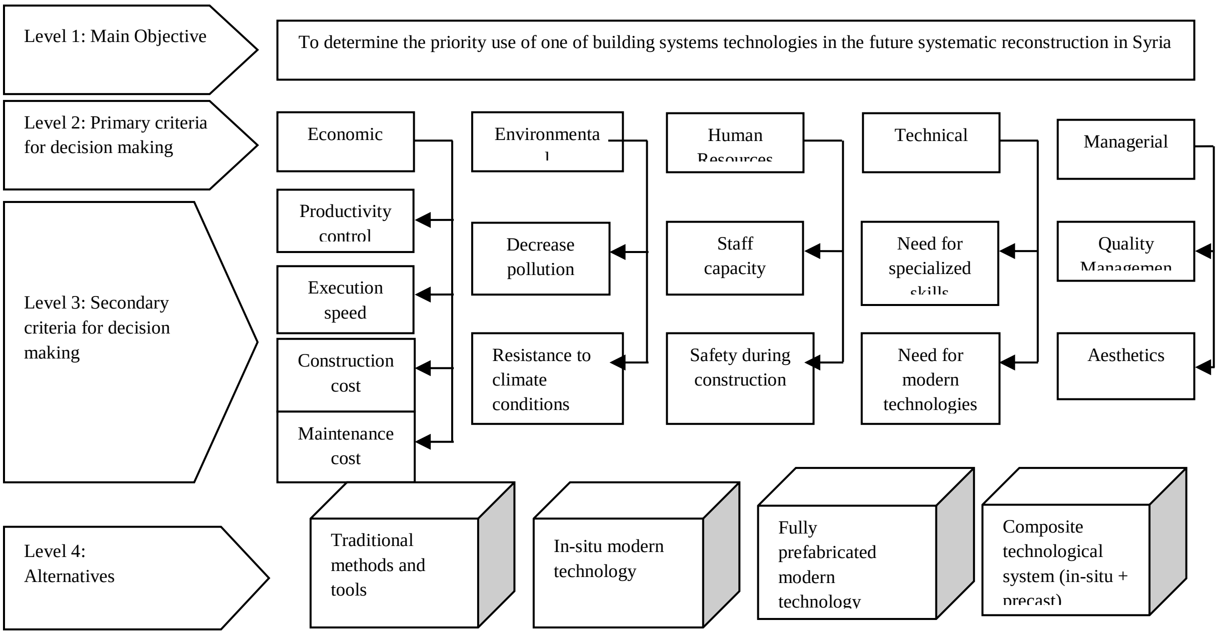

Figure 4: Hierarchical analysis to determine the priority alternative (Source: Authors' illustration, 2015).

3. Conclusions and Recommendations

This paper looked at the definition and classification of *IBS* and characterization of their own construction techniques, as this paper discussed the level of the construction industry in the Syrian construction projects, and discussed the evaluation of the factors affecting the construction industry through accurate and comprehensive field study.

Given the importance of existence a comprehensive methodology in Syria to adopt strategic issues for the Syrian construction industry, we have identified priorities for choosing the right technical system for building within the reconstruction system in Syria, and reached the following conclusions and recommendations:

- The use of the building industry systems *IBS* in Syria can offer the benefits of speed, quality and safety for construction projects, and achieve the construction requirements.
- Obtaining a high level in *IBS* requires a move towards industrialization.
- Through the assessment of the IBS value for patterns executive solutions used for buildings in Syria, a system of cast-in-place concrete in the case of reinforced walls had 13.1%, while for cast-in-place concrete in the case of the framework structure it was 34%, the composite system (pre-cast and cast-in- place) had 61%, tunneling templates had 64%, for the composite system (concrete and metal) it was 67.25%, and pre-cast concrete gained from 82% up to 86%.
- *IBS* is facing significant challenges in Syria, according to the survey results, which showed a significant reduction in the current application of most of the factors affecting the construction industry.
- Using the method of *AHP*, the advanced technology prefabricated system was on first place with 39.4%, followed by the composite technical system (cast-in- place + pre-cast) with 21.8%, in third place advanced cast-in-place technology with 20.8%, as stated in last rank were traditional methods and tools.

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Time and Cost Overrun in Public Construction Projects in Qatar

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Abstract

This paper investigate time delays and cost overruns in public construction projects in the State of Qatar using statistical relationships between project contracted costs or durations and other variables. An extensive review of regional and international case studies was conducted to get a better understanding of the phenomena and of the various methodologies used to analyze it. The data of the study, which was collected from Qatar public work authority ASHGHAL, covered 122 public roads, buildings, and drainage projects. The Analysis Of Variance (ANOVA) statistical technique was used for the data analysis and inference. Several models were developed based on project type, duration, and cost. However, the models were limited in scope. Therefore, future work will involve adding more variables into the current models.

Keywords: Cost Overrun, Construction Delays, Qatar Public Projects, Statistical Analysis

1. Introduction

Changes are facts of the construction process. They are issued to respond to newly developed circumstances. Large and poorly managed changes may have tremendous negative impacts on project time and cost performances. One of the major problems facing the construction industry is project frequent delays and cost overruns. In today's economic boom times and highly competitive business environment, the need for completing construction projects within the stipulated cost, time frame and performance expectations is becoming increasingly important. Delays and cost overruns extend the duration of a project, inflate the budget, reduce revenues, and degrade productivity.

In the state of Qatar, the public projects, which were performed during the period between 2000 and 2013, had a 54% cost overrun and a 72% time delay of 72%. On the other hand, the maintenance projects during the same period had both 50% cost overrun and time delay. Thus, there is a real need to investigate time delays and cost overruns in Qatar public construction projects because of their criticality and the limited number of published studies in this area.

2. Objectives ad Methodology

2.1. *Objectives*

The main objective of the study is determine and analyze the time delays and cost overruns commonly found in Qatar public projects. The scope of the study is limited to public construction projects whose data were obtained from public work authority (ASHGHAL).

2.2. *Methodology*

The methodology consisted of data collecting, data mining, performing statistical analysis and building conclusions based on statistical findings. The data was requested from the Public Work Authority ASHGHAL. A total of 122 projects were studied with a focus on the construction phase only. All the construction projects were

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completed between the years 2000 and 2013 and all claims settled by 2013. All construction projects were lump sum contracts and had the traditional delivery method of design-bid-build.

The collected data included project category, project type, contract cost, contract duration, duration and cost at completion at completion. Time and cost overrun percentages had been calculated, using this data.

The data was studied using the Analysis of Variance (ANOVA).

3. Literature Review

Cost overruns, deadline delays, delivery delays, poor quality of materials, poor workmanship, and low productivity, are inevitable in the construction industry. Time delays and cost overruns usually lead to adverse effects on the growth of national economies, contribute to major financial losses, and hold back the development of the industry. A long-term study of a number public works projects, which was conducted in the state of Nevada in the United States showed the negative and costly impacts of such time delays. It investigated several design-bid-build state projects from 1991 to 2008 and concluded that large and long-duration projects had significantly higher cost and schedule overruns than smaller and short-duration projects [1]. The project aspects such as scope definition, coordination of roles and responsibilities among involved parties, initial estimation and contingency planning, and monitoring and control systems are the main factors for time delays and cost overruns [2]. Most construction projects in developing countries are characterized by time delays [3]. The projects with extensive delays may end up losing their economic justification, which in turn may result in the termination of the project [4]. The following complications due to delays increase in governmental projects were identified: 1) confusion regarding public development plans, 2) disturbance of the budget execution plan, and 3) public inconvenience resulting from project delays [5].

The following major causes of construction/delivery delays were reported: 1) insufficient data collection and survey before design, 2) higher than expected increase in costs due to inflation, and 3) repair/reconstruction work due to errors during construction [4]. The three most important causes for construction delay were improper planning, poor site management, and inadequate and/or limited experience [6].

The majority of cost overruns are encountered in lump sum contracts, fewer occur in unit-price contracts and even less in reimbursement contracts [7]. They reported the following causes of cost overruns: 1) awarding contracts to the lowest bidder; 2) site conditions; 3) incompetent subcontractors and poor site management; and 4) inaccurate estimates and client-led change orders. The following major cause of cost overruns were identified: 1) market conditions, 2) personal experience in the contract work, 3) insufficient estimated time for construction items, 4) material fluctuation, and 4) political situations [8].

Qatar is one of the fastest growing GDP in the world. Moreover, Qatar has the highest saving rate in the world, with a saving percentage of 60.8% of GDP. The construction industry showed the second largest growth in 2013 by contributing 2.7% to the non-hydrocarbon GDP growth. The construction activities have been expanding rapidly to be completed ahead of FIFA World Cup in 2022. Qatar is currently constructing major infrastructure projects such as Doha metro, a network of expressways, Sharq crossing, several tunnels and bridges, crossing Doha bay. Moreover, several real estate projects are underway in Lusail city, to the north of Doha. The Qatari construction sector is suffering delay and cost overruns. New projects are experiencing 54% cost overrun and 72% delay. On the other hand, the maintenance projects are experiencing 50% for both cost overrun and delay.

The $1.7 billion project, which aimed to convert a jammed traffic road into a new layout of junctions, underpasses and bridges was a nightmare for vehicle movement and shops running along since construction began in 2010. The initial target was due to the end of 2012. However, the date was pushed to the third quarter of 2013.

The long-awaited Hamad International airport, $15.5 billion planned investment $15.5bn was delayed four years. It was partially opened in April 2014, with a later phase expected to finish by year 2017-2018.

Possible justifications to project delays were reported as poor management and control systems, manpower low quality, construction material and equipment shortage, inappropriate estimation of massive scale of projects, harsh summers, and funding constraints of private projects. Public projects are also suffering from imposed changes and unclear work scope and objectives.

4. Data Collection and Analysis Methods

4.1. *Data Collection*

Several meetings were conducted with head of departments to discuss the project and get needed approvals. Several other meetings were conducted with project managers and planning engineers to discuss the topic and get more clarifications through discussing some cases and followed procedures at ASHGHAL. Once the approval was gained, proposed data had been sent to the student.

Qatari public projects are classified in to roads, buildings and drainage projects, and being categorized as new construction or maintenance projects. Road projects include the design, construction, delivery, and maintenance of all expressways, major and minor roads all over the country. The same role applies to public buildings for a number of government entities, including schools, hospitals, parks and cultural centers. Drainage projects represent storm and rain water, waste water and sewerage drainage and treatment projects across Qatar.

The data for 122 projects was received from ASHGHAL. The collected projects started in or after the year 2000 and were completed before or on the year 2013. Their contract were lump sum and their delivery method were design-bid-build.

The collected data included the project category, project type, contract cost, contract duration as well as the duration and cost at completion. The durations were measured in calendar days and costs in Qatari Riyals. Road projects represented 67% of total received data, 21% of building projects, and 12% drainage projects. All drainage projects were new construction.

4.2. *Analysis Methods*

Statistical analysis was used to compare samples. ANOVA was used to determine if differences were statistically significant. The confidence level selected for the analysis was set to 95%.

ANOVA assumed a null hypothesis, assuming that the means of compared samples are to be statistically equal. For the null hypothesis to be false, the p-value must be less than or equal to 0.05. Given that the null hypothesis is true, the p-value represents the probability of observing a random sample that is at least as large as the observed sample.

If the p-value is below 0.05, the difference in means is considered to be statistically significant (Weinstein, 2007).

This study covered the three projects types, road, building and drainage construction projects, in which, cost and time overrun percentages were compared based on five categories as follows:

- Project Type: road, building, drainage
- Project Category: new construction, maintenance construction
- Project Size: final cost less than or equal QR10 million; final cost between QR10–QR100 million; final cost between QR100–QR1000 million, final cost greater than QR1 billion.
- Project Duration: duration less than or equal 1 year; duration between 1 and 2 years; duration between 2 and 3 years; duration between 3 and 4 years; duration greater than 4 years)
- Project Year of Completion: completed between 2000 and 2006; completed between 2007 and 2013.

When the multiple groups were identified, a single factor ANOVA test was carried between the groups of highest and lowest means.

5. Result Analysis

Statistical tests were used to determine the descriptive statistics of the dependent variables. The first test was to investigate whether the sample means of various groups were statistically different or of equal variances. For this goal, MS-Excel 2007 ANOVA tool had been used.

The statistical differences between project cost and time overrun percentages as per different classification methods are tabulated in this section.

5.1. *Project Type*

Table 1 shows the ANOVA analysis of the construction cost and time overruns for the different project types. The means of the cost and time overruns of building, road, and drainage projects were not statistically significant at a significant level of 0.05, as the P value of both metrics are larger than 0.05 (0.05<0.233 and 0.05<0.316). Therefore, the sample means were not statistically different.

Table 1. ANOVA project type

Metrics	Building	Road	Drainage	F Value	P Value	F Critical
Cost Overrun (%)	0.703	0.182	0.108	1.493	0.233	3.153
Number of Projects	14	40	8	Not Significant		
Time Overrun (%)	2.616	0.815	0.782	1.170	0.316	3.120
Number of Projects	18	51	8	Not Significant		

5.2. *Project Category*

Table 2 shows the ANOVA analysis of the construction cost and time overruns for the different projects categories. Although the cost overrun and time overruns were higher in new projects than in maintenance projects, the means were not statistically different. In another expression, new and maintenance projects were not statistically significant at a significant level of 0.05 (0.05 <0.473 and 0.05<0.363).

Table 2. ANOVA project category

Metrics	New	Maintenance	F Value	P Value	F Critical
Cost Overrun (%)	0.365	0.170	0.521	0.473	4.001
Number of Projects	38	24	Not Significant		
Time Overrun (%)	1.560	0.590	0.837	0.363	3.968
Number of Projects	51	26	Not Significant		

5.3. *Project Category*

Table 3 shows the ANOVA analysis of the construction cost and time overruns for the different building project categories. The cost overrun mean for new projects was higher than in maintenance projects. On the other hand, the time overrun mean for maintenance projects was higher than that for new projects. However, in both cases, new and maintenance projects were not statistically different at a significance level (0.05 <0.515 and 0.05<0.658).

Table 3. ANOVA building project category

Metrics	New	Maintenance	F Value	P Value	F Critical
Cost Overrun (%)	0.953	0.078	0.451	0.515	4.747
Number of Projects	10	4	Not Significant		
Time Overrun (%)	0.412	3.057	0.204	0.658	4.494
Number of Projects	3	15	Not Significant		

5.4. *Road Project Category*

Table 4 shows the ANOVA analysis of the construction cost and time overruns for the different road project categories. The maintenance road projects had higher cost and time overrun means. However the new and maintenance projects were not statistically significant at a significance level of 0.05. (0.05 <0.805 and 0.05<0.099)

Table 4. ANOVA road project category

Metrics	New	Maintenance	F Value	P Value	F Critical
Cost Overrun (%)	0.953	0.078	0.451	0.515	4.747
Number of Projects	10	4	Not Significant		
Time Overrun (%)	0.412	3.057	0.204	0.658	4.494
Number of Projects	3	15	Not Significant		

5.5. *Project Size Category*

Table 5.5 shows the ANOVA analysis of the construction cost and time overruns for the different projects sizes. The cost and time overruns for project size ranges between QR10 million to QR100 million were the highest. However, the mean differences were not statistically significant at a significance level of 0.05 (0.05< 0.883 and 0.05<0.896).

Table 5.5. ANOVA project size

Metrics	Less than 1 million QRs	10 to 100 Million QRs	100 to 1000 Million QRs	Larger than 1 billion QRs	F Value	P Value	F Critical
Cost Overrun (%)	0.148	0.387	0.193	0.120	0.219	0.883	2.764
Number of Projects	10	34	16	2	Not Significant		
Time Overrun (%)	0.778	1.591	0.845	0.659	0.200	0.896	2.730
Number of Projects	14	42	18	3	Not Significant		

5.6. *Project Duration Category*

Table 5.6 shows the ANOVA analysis of the construction cost and time overruns for the different projects durations.
The construction cost and overrun means for projects with 1 to 2 years durations were the highest, with a noticeable difference to cost overrun percentages of other durations. All were not statistically significant at a significance level of 0.05 (0.05<0.797 and 0.05<0.946).

Table 5.6. ANOVA project duration

Metrics	Less than 1 year	1 to 2 years	2 to 3 years	3 to 4 years	Larger than 4 years	F Value	P Value	F Critical
Cost Overrun (%)	0.140	0.518	0.143	0.238	0.150	0.416	0.797	2.534
Number of Projects	12	22	13	9	6	Not Significant		
Time Overrun (%)	0.554	1.648	0.907	0.902	1.662	0.183	0.946	2.499
Number of Projects	11	32	17	10	7	Not Significant		

5.7. *Project Year of Completion Category*

Table 5.7 shows the ANOVA analysis of the construction cost and time overruns for the different project completion years. The cost overrun mean of the projects that were completed between 2007 and 2013 were lower than those of the projects that were completed between 2000 and 2006. The P value was less than the significance level (0.05>0.021). This shows that the sample means were statically different at a significance level of 0.05. On the other hand, the time overrun mean of the projects that were completed between 2007 and 2013 were higher than those of the projects that were completed between 2000 and 2006. However, the means were not statistically different at a significance level of 0.05 (0.05<0.099).

Table 7. ANOVA project year of completion category

Metrics	2000 to 2006	2007 to 2013	F Value	P Value	F Critical
Cost Overrun (%)	0.900	0.143	5.606	0.021	4.001
Number of Projects	12	50	Not Significant		
Time Overrun (%)	2.677	0.759	2.792	0.099	3.968
Number of Projects	19	58	Not Significant		

6. Conclusions

This present study investigated time and cost overruns in Qatari construction projects. An extensive literature review was conducted to regional and international case studies, to achieve a better understanding of the phenomena while inspecting various methodologies performed for different goals. Extensive data was collected from 122 construction projects that were from the Public work authority ASHGHAL. The ANOVA statistical analysis method was used for the data analysis and inference. The statistical analysis results show that the cost and time overrun means were not significant at a significance level of 0.05 with respect to the project type (i.e., building, road, and drainage). The results also show that the new and maintenance projects were not statistically significant at a significant level of 0.05. Moreover, they show that the cost and time overruns were not significant at a significance level of 0.05 with respect to the project size and project duration. Finally, the ANOVA statistical results show that the construction project cost overruns were statistically significant at a significance level of 0.05 with respect to their year of completion. In other words, the construction project cost overruns for the project completed between 2007 and 2013 are lower than those completed between 2000 and 2007.

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Preliminary Resource-based Estimates Combining Artificial Intelligence Approaches and Traditional Techniques

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Abstract

The fate of many construction projects is determined using preliminary project cost estimates. These estimates play a key role during the conceptual phase of projects; as in many cases they are the primary element used to decide their viability. The lack of information and the high levels of uncertainty with what will be done in the project, during the conceptual phase, make it infeasible to have reliable building information models that could be used to generate quantity takeoffs for preliminary cost estimates (known in the industry as 5D BIM), in line with a Level 2 BIM maturity. This paper presents a way to combine artificial intelligence (case-based reasoning and neural networks), with traditional techniques (regression analysis), to develop accurate estimates of the resources needed in a project (e.g., construction material quantities). These estimates of resources can then be coupled with unit cost information to make preliminary resource-based cost estimates. The clear division between the technical and financial components of such an estimate give improved decision support to project managers and decision makers. This enhances the tracking and control mechanisms which could be used to check the estimates prepared in subsequent project phases. The combination of case-based reasoning with regression analysis and the use of neural networks has shown an improved performance in the estimation of the amount construction material quantities. The proposed combination was used to estimate the amount of concrete, reinforcement, and structural steel required for the construction of tall-frame structures. The results show lower errors (overall mean absolute percentage error-MAPE) for the combined models (2.55%) when compared to the regression models (12.01%), neural network models (5.84%), and case-based reasoning models (9.30%). This type of estimates will help keep construction projects on schedule and on budget.

Keywords: case-based reasoning; hybrid estimation models; neural networks; regression analysis; preliminary estimates of resources.

1. Introduction

In the majority of projects requiring the use of significant amounts of capital, both financial and labor, the norm is that projects have a tendency to costs more than originally planned. Studies ([1], [2]) have shown that using current cost estimating practices over 80% of the projects investigated from different industries (e.g., oil and gas, chemical, power and utilities, mining and metals, EPC contractors, manufacturing, telecommunications, government and defense, transportation) were over budget with actual cost exceeding 40% of the original estimated amounts. This is not limited to a particular sector or country, but a general phenomenon that occurs in most industries and in most nations. In some cases if the true value of the construction costs were known at the approval stage, the project may not have been approved. In addition, cost estimates have not improved and cost overruns not decreased over the past 70 years ([3]).

Preliminary cost estimates are the first thoughtful efforts to predict the cost of a project and they are crucial to the initial decision-making process for the construction of projects. These estimates heavily influence the fate of many projects, yet they have many limitations. Estimators at these early stages of a project's life cycle are typically provided with very little information about the project, limited scope definition, and very little time to prepare this kind of estimates.

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Preliminary cost estimates are typically carried out to support project evaluations, engineering designs, cost budgeting and cost management. Many methods have been developed in various industries to evaluate costs at pre-design stage ([4], [5]). In most cases, construction and infrastructure managers make estimates based heavily on their expert knowledge, missing the full use of the information that they possess and using a great amount of time and effort. In addition, cost estimating is a tedious and time-consuming quantification process, prone to human error which tends to propagate inaccuracies into the different line items of an estimate.

2. State of the art

The estimation models used can be very rudimentary or highly complex and proprietary. Many techniques for the estimation of construction cost have been employed by researchers and practitioners. While most practitioners use models based on regression analysis (RA) or make estimates based on their experience, some researchers and sophisticated owners and contractors use artificial intelligence (AI) techniques, such as neural networks (NNs), and case-based reasoning (CBR). In some cases, combinations of techniques have been used.

The concept of combining estimates to improve the estimation in not new. [6] suggested combining estimates through regression. However, it was the work of [7] and [8] that provided the initial impetus to the development of a theory in the combination of estimates. Combining estimates is especially useful when it is not clear which method would provide more accurate ones ([9]).

The purpose of combining estimates is to use each model's unique features to capture different patterns or features in the data set ([10]) and by combining estimates from different models, the accuracy can often be improved over the individual estimate ([11]). In the construction industry, the concept of combing different techniques has been explored by different researchers to develop cost estimates (Table 8).

Table 8: Combination of different techniques to develop cost estimates in the construction industry

Source	Estimate for	Combination of
[12]Choi et al. (2013)	Cost of public roads in Korea	RST, CBR, and GA
[13] and [14]Jin et al. (2012) and Jin et al. (2014)	Cost of construction projects	CBR and MRA
[15]Kim (2013)	Cost of highway projects in South Korea	AHP and CBR
[16]Kim and Shim (2013)	Cost of high-rise buildings in South Korea	GA, CBR
[17]Kim et al. (2005)	Cost of residential buildings in Seoul, Korea	NN and GA
[18]Koo et al. (2010)	Cost and duration of multi-family housing projects in Korea	CBR, MRA, NN, and GA

Legend: NN: Neural network; GA: Genetic algorithm; CBR: Case-based reasoning; NFS: Neuro Fuzzy System; AHP: Analytic Hierarchy Process; MRA: Multiple Regression Analysis; RST: Rough Set Theory

Although the combination of techniques to develop cost estimates provided good results, these estimates typically provide a single monetary value and they lack the information needed to make meaningful comparisons with other, more accurate, estimates developed during the project's life cycle. This also affects the information used in the different control tools available to project managers and limits applications (lessons learned) for future projects.

The construction industry should take full advantage of new techniques and borrow expertise from other fields to implement methods such as AI, and adopt newer technologies, such as digital modeling software that allows computer generation of n-dimensional models (generally associated with Building Information Modeling) to improve the accuracy and reliability of preliminary cost estimates. To this end, a way to assist the estimator in the preparation of reliable and traceable estimates made during the project conception phase of construction projects is presented in this paper that shows a way to develop preliminary estimates for resources (e.g., construction material quantities-CMQs) combining AI approaches (e.g., NNs and CBR) and traditional techniques (e.g., RA).

As done by other researchers (e.g., [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31]) the preliminary estimates were made for the amount of resources (e.g., CMQs) to be used in a given project so that there is a clear separation between technical estimates (e.g., quantities) and market fluctuations (e.g., cost of materials and labor).

3. Combination of AI approaches and traditional techniques

In the study presented in this paper, RA, NNs, and CBR were used to make preliminary CMQ estimates in a systematic, reliable, and accurate manner. Multiple regression was used to develop regression models using a particular type of nonlinear relationship (Equation (1)), known as the constant elasticity or multiplicative relationship ([32]).

$$Y = \left(X_1^{\beta_1} X_2^{\beta_2} \ldots X_n^{\beta_n} \right) e^{\left(\beta_0 + \sum_{j=1}^{m} \beta_{n+j} X_{n+j} + \frac{SEE^2}{2} \right)} \tag{1}$$

Where,

Y :	Output from the regression equation
β_o :	Constant
$\beta_1 \rightarrow \beta_n$:	Coefficients for continuous variables
$\beta_{n+1} \rightarrow \beta_{n+m}$:	Coefficients for categorical variables
$X_1 \rightarrow X_n$:	Continuous independent variables
$X_{(n+1)} \rightarrow X_{(n+m)}$:	Categorical independent variables
e :	Euler's number
SEE :	Standard error of the estimate

The NN models developed were fully connected feed-forward network with three layers (one hidden layer) using the back-propagation supervised learning algorithm. The independent variables from the regression models were used as the neurons in the input layer.

CBR was used with its four phases, namely retrieve, reuse, revise and retain [33]. The retrieve and revise (i.e., adaptation) phases were modified using information from the regression models.

The combination of the AI approaches and traditional techniques is summarized in Figure 10. The coefficients from the developed regression models for a given CMQ were used by the retrieval and adaptation phases in CBR, and the independent variables (IVs) were used to determine the neurons in the input layer of the NN models, which provided better results for complex and highly non-linear cases. These models were also used to perform direct estimations in the cases where similar structures were not found using CBR (i.e., CBR cannot be used).

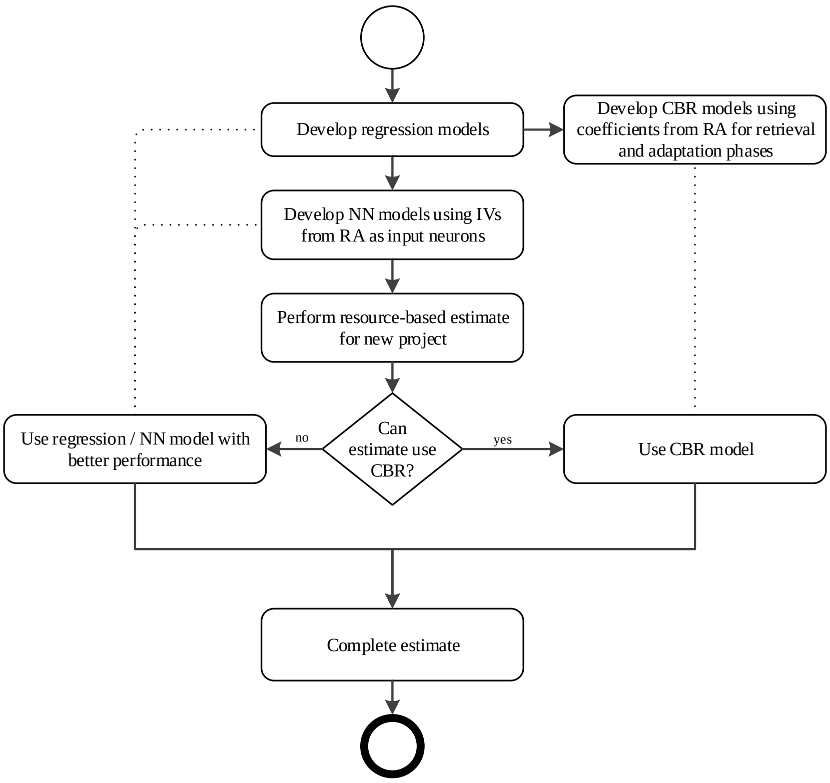

Figure 10: Interaction among the different techniques used to make CMQ estimates

Three basic concepts were kept in mind when developing a way to develop CMQ estimates, they were: learning, adjusting and estimating. These concepts were integrated by combining RA and AI.

3.1. *Learning from historical data*

The combined techniques made use of the CMQs of existing structures to estimate the CMQs of target structures, i.e., the ones for which the CMQs are to be estimated. The target structures were compared to the existing ones by determining their similarity based on the values of numerous parameters. The most similar structures were used as the basis of the estimate for the target structures.

This was done by using CBR, in particular during the retrieval process. The proposed retrieval process used the city-block distance with the adjusted unstandardized coefficients obtained from RA as shown in [34].

3.2. *Adaptation of proposed results*

The CMQs of the similar existing structures were adapted. This adaptation accounted for the differences between the target and the existing structures by adjusting the proposed estimation of CMQs for the target structure when applying the selected estimation model. This adaptation was done by incorporating a systematic process in which the regression models were used as the basis of the adaptation process. More information about this adaptation process can be found in [35].

3.3. *Direct estimation*

Estimates of the CMQs, if no similar structures were found, was done by directly using either the regression of the NN model developed. More information about the development and evaluation of estimation models using RA and NN can be found in [31].

4. Estimate CMQs for a new project

The CMQs for the structures in the target project were estimated using a combination of RA, NN, and CBR, which interacted with each other to provide accurate results. The coefficients from the developed regression models for a given CMQ were used by the retrieval and adaptation phases in CBR, and the independent variables (IVs) were used to determine the neurons in the input layer of the NN models which provided better results for complex and highly non-linear cases. These models were used to perform direct estimations in the cases where there were not similar structures identified using CBR (Figure 10).

Using CBR, similar structures were identified and used as the bases for the new estimate. This provided the transfer of knowledge (i.e., learning from historical data) to this process. The CMQs from the similar existing structures were adjusted to take into consideration the differences between the values of the input parameters from the target structure and the similar existing structures. In the cases where CBR was not applicable, either RA models or NN models were employed to complete the estimate of CMQs for the new project. Throughout this phase the "bases for the estimated CMQs" (e.g., the parameters used and the assumptions relied upon in the estimating process) was tracked and documented.

4.1. *Implementation*

Models were developed using RA, NN, and CBR to estimate the amount of CMQs required in the construction of the upper structure and foundation of tall-frame structures. The information used to develop the models was limited to the information that would be readily available to the estimator during the early stages of a project. The tall-frame structures had a rectangular area and were built of reinforced concrete and structural steel. A total of 148 tall-frame structures with the characteristics shown in Table 9 were used for model development and model testing. The set was randomly divided into a set of 118 for testing and 30 for testing the model.

Table 9: Characteristics of tall-frame structures used to estimate CMQs

Parameter	Max	Min	Average
Height (m)	158	94	134
Footprint (m^2)	150	35	84
Wind speed (m/s)	54	31	41
Ground acc. (S_1xg)	1.32	1.02	1.16
Soil BC (t/m^2)	65	20	37
Concrete (m^3)	11,560	2,814	5,288
Rebar (t)	1,879	442	842
Structural steel (t)	734	367	542

The regression and NN models for each CMQ are summarized in Table 10 and Table 11 respectively. Table 10 shows the coefficients from the regression models for the different materials estimated. Table 11 shows the weights between the input and hidden layer and hidden layer and output layer for the different NN models developed for each CMQ.

Table 10: Regression models for the estimation of CMQs of tall-frame structures

	Concrete (m^2)			Reinforcement (tons)			Structural steel (tons)		
	Unstandardized Coefficients		Standardized Coefficients	Unstandardized Coefficients		Standardized Coefficients	Unstandardized Coefficients		Standardized Coefficients
Variables	β	Std. Error	Beta	β	Std. Error	Beta	β	Std. Error	Beta
(Constant)	1.27E+00	8.00E-02		-8.17E-01	8.10E-02		6.88E+00	4.50E-02	
Height (m)	1.36E+00	1.60E-02	4.20E-01	1.46E+00	1.60E-02	4.23E-01	-9.20E-02	9.00E-03	-5.10E-02
Footprint (m^2)	3.23E-01	5.00E-03	1.86E-01	3.03E-01	5.00E-03	1.64E-01	2.30E-02	3.00E-03	2.40E-02
Wind speed (m/s)	-6.00E-03	6.00E-03	-3.00E-03	-7.00E-03	6.00E-03	-3.00E-03	2.00E-03	4.00E-03	1.00E-03
Ground acc. (S_1xg)	-1.83E-01	2.00E-03	-2.23E-01	-3.53E-01	2.00E-03	-4.03E-01	-1.60E-01	3.00E-03	-3.27E-01
Soil BC (t/m^2)	-1.50E-01	5.00E-03	-1.74E-01	-1.43E-01	5.00E-03	-1.56E-01	1.80E-02	2.00E-03	3.70E-02

Table 11: NN models for the estimation of CMQs of tall-frame structures

		Concrete (m^2)				Reinforcement (tons)				Structural steel (tons)			
Input		Input/Hidden Layer (W_A)			Output Layer	Hidden Layer (W_A)			Output Layer	Input/Hidden Layer (W_A)			Output Layer
		H_1	H_2	H_3	Concrete (m^3)	H_1	H_2	H_3	Reinforce-ment (t)	H_1	H_2	H_3	Structural steel (t)
Input Layer	I_1: Height (m)	8.20E-02	-6.80E-01	-3.71E-01		-2.40E-01	-4.48E-01	4.30E-01		-9.33E-01	4.05E-01	1.06E-01	
	I_2: Footprint (m^2)	1.72E-01	2.38E-01	-6.80E-01		-7.10E-02	-1.42E-01	-1.76E-01		1.82E-01	-1.48E-01	-1.02E-01	
	I_3: Wind speed (m/s)	-3.00E-03	2.02E-01	-2.00E-03		1.10E-01	4.90E-02	3.30E-01		-9.24E-01	1.00E-02	3.54E-01	
	I_4: Ground acc. (S_1xg)	-1.10E-02	-1.27E-01	-1.37E-01		3.90E-02	-7.70E-01	3.50E-02		1.87E-01	-1.14E+00	-3.43E-01	
	I_5: Soil BC (t/m^2)	4.73E-01	-1.02E-01	3.36E-01		-4.44E-01	9.29E-01	-5.36E-01		3.94E-01	4.86E-01	-1.30E-02	
	Bias 1	-1.95E-01	5.90E-02	6.06E-01		1.56E-01	-2.40E-01	-4.78E-01		-1.08E+00	9.26E-01	4.90E-02	
Hidden/Out-put Layer (W_B)	H_1				8.29E-01				-1.15E+00				-9.43E-01
	H_2				-5.86E-01				-5.08E-01				-1.15E+00
	H_3				-4.23E-01				-4.20E-01				-5.24E-01
	Bias 2				-1.56E-01				-6.73E-01				-9.00E-03

4.2. *Results*

The results obtained for the estimation of the amount of concrete, reinforcement, and structural steel using the combination of CBR, RA and NN models showed a close agreement between the actual and estimated amounts. An example is shown in Figure 11 for the amount of structural steel as can be seen by the closeness between the actual and estimated amounts.

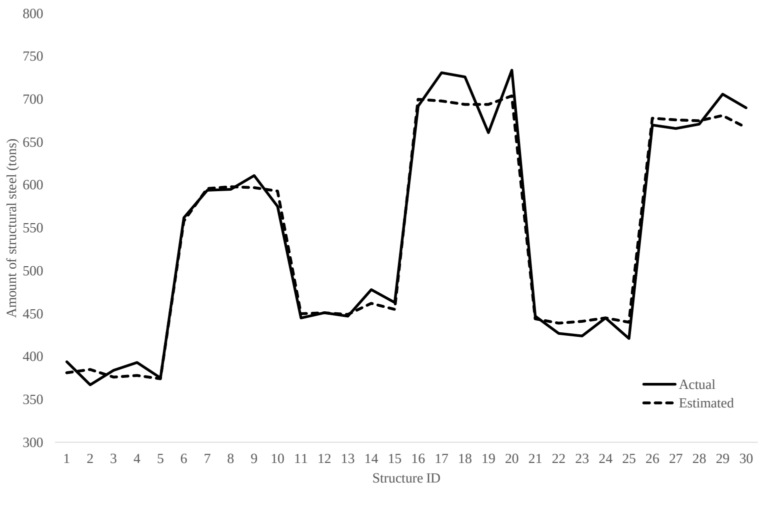

Figure 11: Actual and estimated amount of structural steel for the construction of tall-frame structures

The mean absolute percentage error (MAPE) of the estimates using the combination of CBR, RA, and NN was lower that the MAPE for the stand-alone models (i.e., without combination) for all CMQs estimated (Table 12).

Table 12: MAPE for estimated CMQs with and without combination of AI approached and traditional techniques

	Model type			
CMQ	Combined (CBR, RA, NN)	RA	NN	CBR
Concrete (m^2)	2.73%	12.58%	8.65%	9.09%
Reinforcement (tons)	2.60%	11.39%	4.86%	9.56%
Structural steel (tons)	2.31%	12.07%	4.01%	9.24%
Overall MAPE	2.55%	12.01%	5.84%	9.30%

5. Conclusion

The combination of AI approaches and traditional techniques has proven to be an appropriate way to develop estimates of the resources needed in a construction, such as the amount of CMQs required. These estimates of resources can then be coupled with cost information to get preliminary resource-based cost estimates with a clear division between the technical and financial components. This type of estimates give better decision support to project managers and decision makers, and subsequently, enhance the tracking and control mechanisms used in subsequent project phases. The combination of RA, with NN and CBR has shown an improved performance in the estimation of CMQs of tall-frame structures when compared to the performance of these techniques alone as shown by the overall MAPE for the combined models (2.55%), regression models (12.01%), NN models (5.84%), and CBR models (9.30%). Although the implementation has been made for tall-frame structures, this approach could be suited for other structure types and other resources.

The three concepts of learning, adjusting and estimating have been successfully integrated by combining RA and AI by using the coefficients from the developed regression models during the retrieval and adaptation phases in CBR, and the independent variables from the regression models as the neurons in the input layer of the NN models. Even in cases where CBR was not able to find similar existing cases, estimations were also possible by using the appropriate regression or NN model.

This idea of combination of techniques to develop resource-based cost estimates has a wide ranging potential to be used for other types of infrastructure and many other types of projects. The development of preliminary estimates in this way will help estimators to make better estimates, and armed with this information, allow managers to make better decisions of what should be done and when.

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Urban Renewal Project Selection Using the Integration of AHP and PROMETHEE Approaches

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Abstract

Appropriate project selection has a significant impact on construction companies' success. Selecting the appropriate project is complicated due to uncertainties related to many factors that may influence the project selection process. The uncertainties related to a construction project may vary according to the type of the construction project. Therefore, having a project selection tool, which assists construction companies in selecting a particular construction project, can be a significant advantage in achieving success. Urban renewal projects constitute a significant portion of the projects that are carried out by construction companies in Turkey. This study aims to propose an integrated approach for selection of urban renewal projects. The proposed approach combines analytic hierarchy process (AHP) method and PROMETHEE, to help construction companies in selecting the appropriate urban renewal project. AHP and PROMETHEE were used to find the weights of the selection criteria and to rank the alternative projects, respectively. The proposed approach is used to solve a project selection problem of a Turkish construction company, which is mainly specialized in urban renewal projects. In the case study, twelve different projects were ranked according to seventeen evaluation criteria by using the proposed approach. The findings of this study revealed that the proposed approach can be a useful tool for construction companies, which are especially specialized on urban renewal projects.

Keywords: Analytic hierarchy process; case study; project selection, promethee; urban renewal projects

1. Introduction

Turkey is one of the most earthquake-prone countries in the world. Due to having too many buildings (e.g., public buildings, residential buildings, etc.) that are not safe enough to survive during a major earthquake, Istanbul has become a specific focus of many urban renewal projects. In typical urban renewal projects, public authorities purchase properties from many different private owners, renew and resell them to other private owners [1,2]. However, it should be noted that the execution of urban renewal projects is different in Turkey from the execution of typical urban renewal projects due to the regulations established by public authorities. In Turkey, public authorities are not involved in purchasing, renewing and reselling of properties, but establishing the regulations guiding the planning and execution of urban renewal projects. Inhabitants, who are residing in urban renewal districts that are specified by law, hire a contractor to renew their buildings. The contractor agrees to rebuild the building in return for owning a number of units. In order to support the renewal of unsafe buildings, the regulations guiding the planning and execution of urban renewal projects allow the owners to build more square meters when they hire a contractor to renew their building. Contractors are responsible for the cost of the project in return for a number of units to sell.

At this point, selecting appropriate urban renewal project gains importance for contractors as they take more risk than any party involved. Several studies have been conducted on developing a model for project selection over the last years [2-7]. Developing a generic model for selecting the most appropriate project is difficult due to the

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fact that factors affecting the selection of a construction project may vary according to the type of the construction project. Therefore, in today's competitive construction environment, construction companies can take advantage of having a tool assisting them in selection of a particular type of the construction project. Since urban renewal projects constitute an important portion of the construction projects that are carried out by construction companies in Turkey, this study aims to propose an integrated approach for selection of urban renewal projects. The proposed approach combines analytic hierarchy process (AHP) method and PROMETHEE, to help construction companies in selecting the most appropriate urban renewal project. In the proposed approach, AHP is used to calculate the weights of the factors and PROMETHEE is used to rank the alternative urban renewal projects. The proposed approach is also applied in a construction company that is mainly specialized in urban renewal projects.

2. Research Methodology

The main objective of this study is to propose an approach for selection of urban renewal projects in Turkey. The proposed approach can be adopted and adjusted by any construction company that is interested in urban renewal projects. The tasks that were performed in this study can be summarized as follows: (1) identifying the factors that affect the selection of appropriate urban renewal projects; (2) integrating AHP and PROMETHEE for selection of urban renewal projects; and (3) applying the proposed approach to solve a project selection problem of a Turkish construction company, which is mainly specialized in urban renewal projects. In the following subsections, a brief review of AHP and PROMETHEE methods are presented.

2.1. *The AHP method*

It is acknowledged by the researchers that AHP is one of the most commonly used techniques for solving multi-criteria-decision-making problems since it was developed by Saaty (1980) [8]. The intention in using AHP is to have manageable and measurable components rather than complex and unstructured components for multi-criteria-decision problems. There are mainly five steps of AHP [8]:

- *Defining the decision problem and determining its goal*.
- *Establishing a decision hierarchy*: The hierarchy is comprised of highest, middle, and lowest levels that represent the goal of a decision problem, multiple criteria, and alternatives, respectively. The relationship between the elements of a level with those of the level immediately below is indicated with this hierarchy.
- *Comparing the elements in the corresponding level in pairs*: This comparison is done in terms of the degrees of influence on the specified element in the higher level of the decision hierarchy. A standardized nine-point scale of measurement, which converts human preferences between available alternatives as equal importance, weak importance, strong importance, very strong importance, and absolute importance, is used for multiple pairwise comparisons.
- *Finding the relative priority for each criterion/alternative through synthesizing all of the pairwise comparison matrices*: In this process, first, the normalized pairwise comparison matrix is found by dividing each element of a pairwise comparison matric by its column total. After establishing the normalized pairwise comparison matrix, the average of its elements in each row is calculated to find the priority vector.
- *Determining the consistency ratio (CR) of the pairwise comparisons*: There are four main steps to calculate the CR. The first step is that the weighted matrices should be established through multiplying pairwise comparison matrices by priority vectors. Computing the eigenvalues by dividing all the elements of the weighted sum matrices by their respective priority vector element is the second step in determining the CR. Third, the average of the eigenvalues is calculated to compute the principal eigenvector. Finally, the principal eigenvector is used to compute consistency index which is necessary to calculate CR. Any CR value that is lower than 0.10 is acceptable, if not then the judgement matrix is considered to be inconsistent. In order to obtain a consistent matrix, the pairwise comparisons should be reviewed and altered.

2.2. *The PROMETHEE method*

PROMETHEE is a family of outranking methods which consists of PROMETHEE I for partial ranking of the alternatives, PROMETHEE II for complete ranking of the alternatives, PROMETHEE III for ranking based on interval, PROMETHEE IV for complete or partial ranking of the alternatives when the set of viable solutions is continuous, PROMETHEE V for problems with segmentation constraints, PROMETHEE VI for the human brain representation, PROMETHEE GDSS for group decision-making, PROMETHEE GAIA (Geometrical Analysis for Interactive Aid) for graphical representation, PROMETHEE TRI for dealing with sorting problems, PROMETHEE CLUSTER for nominal classification. These methods mainly deal with ranking of a set of alternatives according to multiple conflicting criteria [9-12].

In this study, three PROMETHEE tools were used to analyze the urban renewal project selection problem, namely PROMETHEE I and PROMETHEE II. Even though there are different versions in PROMETHEE family, all of the versions are mainly based on eight steps [11- 13]:

- *Determining the criteria and the set of possible alternatives of a decision problem*.
- *Determining the weights of the criteria*: There are different techniques that can be used to determine the weights of the criteria, such as AHP which is the method preferred in this study. No matter which technique you use, these weights are non-negative numbers and independent from the measurement units of the criteria. The lower the weight, the less important the criterion.
- *Determining the preference function*: There are six different preference functions that are used in PROMETHEE method, namely, 1) usual, 2) U-shape, 3) V-shape, 4) level, 5) linear, and 6) Gaussian. The main idea behind using these preference functions is to translate the deviation between the evaluations of two alternatives into a preference degree ranging from zero to one, for each criterion.
- *Determining the threshold values for each criterion*: The threshold values that should be computed are the indifference threshold value, the preference threshold value, and the Gaussian threshold value. The value of an indifference threshold represents the largest deviation to consider as negligible on a criterion. On the other hand, the smallest deviation to consider as decisive in the preference of one alternative over another is represented by a preference threshold. The third threshold value, Gaussian threshold, is only used with Gaussian preference function and it represents an intermediate value between the indifference threshold and the preference threshold.
- *Computing aggregated preference indices*.
- *Computing outranking flows*: The computation of outranking flows is a part of the PROMETHEE I partial ranking.
- *Computing net outranking flow*: The computation of outranking flows is a part of the PROMETHEE II complete ranking. The alternative with the higher net flow is considered to be superior.

For a thorough discussion of the PROMETHEE I and II, readers are directed to Brans (1982) [9], who developed them for partial and complete ranking of alternative of a multi-criteria-decision-making problem.

2.3. *AHP-PROMETHEE integrated approach*

The integrated approach presented in this article is based on four main stages. The first stage, which is called data gathering stage, consists of the identification of the criteria that will be used by a construction company in the urban renewal project selection process and the decision hierarchy is developed by the decision-making team, which is responsible for evaluating and/or selecting urban renewal projects. The next stage involves AHP computations, which consist of four steps, namely, forming the pairwise comparison matrices to determine the weights of the criteria determined in the previous stage, determining the values of the elements of the pairwise comparison matrices, calculating the weights of the criteria by using the geometric mean of the values obtained in the previous step, and forming a final pairwise comparison matrix. The calculated weights of the criteria should be approved by the decision-making team. The third stage is based on PROMETHEE computations, which are partial ranking with PROMETHEE I and complete ranking with PROMETHEE II. By using these calculations, the decision-making team determines the preference functions and parameters, and the urban renewal project priorities. In the final stage, the most appropriate urban renewal project is selected through the rankings provided by PROMETHEE I and II.

3. An application of the AHP-PROMETHEE integrated approach: Case study

A real-life case study is used to illustrate the proposed approach. The case study is based on a project selection problem of a Turkish construction company, which is mainly specialized in urban renewal projects. The company intends to select the most appropriate urban renewal project among twelve alternatives. First, the contractor's team consisting of 3 members, who are in charge of the urban renewal project selection process, determined seven main criteria namely, company related factors (MC-1), project related factors (MC-2), cost related factors (MC-3), contract related factors (MC-4), profit related factors (MC-5), management capability related factors (MC-6), finance related factors (MC-7) and seventeen sub-criteria, namely, reputation (SC1-1), gaining experience (SC1-2), experience in similar works (SC2-1), familiarity with the location of the project (SC2-2), size of the project (SC2-3), duration of the project (SC2-4), cost of the construction work (SC3-1), other costs (SC3-2), penalty (SC4-

1), fair contract clauses related to the dispute resolution (SC4-2), rate of return of investment (SC5-1), duration of return of investment (SC5-2), closeness of the construction site to the head office (SC6-1), safety of the construction site (SC6-2), accessibility of the construction site (SC6-3), amount of credit needed (SC7-1), amount of bond needed (SC7-2), which should be taken into account during the project selection process in the case study.

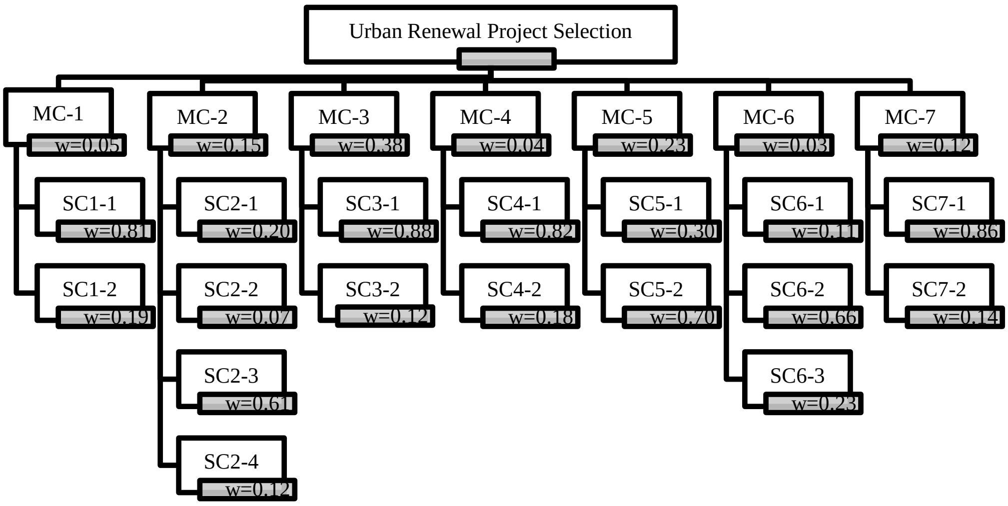

Figure 1. Decision hierarchy of urban renewal project selection problem

3.1. *AHP computations*

After forming the decision hierarchy for project selection problem, the AHP method is used to compute the relative priorities of the criteria. The decision making team individually formed the pairwise comparison matrices and calculated the geometric values of these values to get the final pairwise comparison matrix. As an example, the aggregated pairwise comparison matrix developed for the main criteria is shown in Table 1. Due to the space limitations, the aggregated pairwise comparison matrices established for the sub-criteria could not be presented in the paper. Cost related factors (MC-3), profit related factors (MC-5) and project related factors (MC-2) were found to be the most important criteria in selection of urban renewal projects. Consistency ratio (CR) of the pairwise comparison matrix is calculated as 0.001 < 0.10, which indicates that the judgment matrix is consistent and the weights can be used in the selection process.

Table 1. Pairwise comparison matrix for criteria and results obtained from AHP computations.

Criteria	MC-1	MC-2	MC-3	MC-4	MC-5	MC-6	MC-7	Weights
MC-1	1.00	0.28	0.16	1.59	0.22	2.00	0.30	0.05
MC-2	3.63	1.00	0.25	4.31	0.33	4.64	2.62	0.15
MC-3	6.32	4.00	1.00	7.00	2.62	7.00	4.00	0.38
MC-4	0.63	0.23	0.14	1.00	0.22	1.59	0.25	0.04
MC-5	4.64	3.00	0.38	4.64	1.00	5.31	3.30	0.23
MC-6	0.50	0.22	0.14	0.63	0.19	1.00	0.23	0.03
MC-7	3.30	0.38	0.25	4.00	0.30	4.31	1.00	0.12

3.2. *PROMETHEE computations*

When the AHP computations are over, the first step of the PROMETHEE computations is to form the evaluation matrix. The decision-making team individually evaluated the performances urban renewal project alternatives according to each criterion and the aggregated evaluation matrix, which includes the geometric means of the individual evaluations, is shown in Table 2.

Table 2. Evaluation matrix.

Criteria	Unit	Min/Max	Weights	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12
SC1-1	-	Max	0.04	3.00	9.00	3.30	7.32	6.32	8.32	8.32	9.00	4.31	5.31	2.00	2.00
SC1-2	-	Max	0.01	2.00	6.65	3.30	9.00	9.00	5.65	6.65	6.32	2.52	6.00	4.00	3.30
SC2-1	-	Max	0.03	9.00	9.00	9.00	1.59	2.62	9.00	9.00	9.00	9.00	9.00	9.00	9.00
SC2-2	-	Max	0.01	7.61	9.00	3.30	5.94	1.26	9.00	9.00	9.00	5.65	8.28	3.30	1.26
SC2-3	m^2	Min	0.09	1230	2422	2238	12480	8640	2657	3726	2898	1904	5382	4300	3281
SC2-4	Month	Min	0.02	12	18	18	24	18	16	18	18	16	18	16	18
SC3-1	TL ($x10^3$)	Min	0.33	1845	4844	3917	22419	15920	5314	7452	5796	3332	10764	7310	5742
SC3-2	TL ($x10^3$)	Min	0.04	98	1890	1116	3938	2094	1034	1674	1500	738	1344	524	730
SC4-1	TL ($x10^3$)	Min	0.03	6	30	18	25	20	16	25	25	15	25	15	18
SC4-2	-	Max	0.01	6.32	3.30	6.32	1.59	2.29	4.31	4.31	3.30	6.32	4.64	7.00	8.65
SC5-1	%	Max	0.07	0.85	0.26	0.25	0.25	0.42	0.26	0.25	0.21	0.38	0.39	0.29	0.30
SC5-2	Month	Min	0.16	24	30	30	36	30	28	30	30	24	28	28	30
SC6-1	-	Max	0.01	5.94	9.00	5.94	5.94	3.63	9.00	9.00	8.65	8.65	8.65	3.63	2.00
SC6-2	-	Max	0.02	5.00	9.00	5.31	5.00	3.91	7.32	7.32	9.00	5.31	5.94	2.62	1.00
SC6-3	-	Max	0.01	7.00	4.31	6.65	7.00	3.30	5.59	5.59	4.64	7.00	5.94	5.94	8.00
SC7-1	TL ($x10^3$)	Min	0.10	0	0	0	5000	3000	0	1000	0	0	2000	1000	0
SC7-2	TL ($x10^3$)	Min	0.02	0	3000	3000	5000	4000	3000	3000	3000	2500	3000	2500	2000

The evaluation matrix is the starting point of determining the preference functions and threshold values. They should be determined by considering the nature of the criteria and features of the alternative urban renewal projects. The preference functions and threshold values that are necessary to rank the alternative urban renewal projects are presented in Table 3.

Table 3. Preference functions.

Criteria	Preference Function	Threshold Values		
		q	p	s
SC1-1	Level	1	2	-
SC1-2	Level	1	2	-
SC2-1	Level	1	2	-
SC2-2	Level	1	2	-
SC2-3	Linear	1,000	4,000	-
SC2-4	Linear	4	10	-
SC3-1	Linear	1,500,000	3,000,000	-
SC3-2	Linear	250,000	750,000	-
SC4-1	Linear	10,000	20,000	-
SC4-2	Level	1	2	-
SC5-1	Linear	0.1	0.2	-
SC5-2	Linear	6	10	-
SC6-1	Level	1	2	-
SC6-2	Level	1	2	-
SC6-3	Level	1	2	-
SC7-1	Linear	750,000	1,500,000	-
SC7-2	Linear	1,000,000	3,000,000	-

The following step is the evaluation of alternatives via Decision Lab software, which is used for PROMETHEE computations. When the evaluation matrix, preference functions and thresholds are inputted, this software is capable of performing all calculations efficiently and rapidly. The positive flow ($\boldsymbol{\phi}^{+}$), negative flow ($\boldsymbol{\phi}^{-}$), and net flow ($\boldsymbol{\phi}$) values are obtained through the calculations performed by Decision Lab software (Table 4).

Table 4. PROMETHEE flows.

Alternatives	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12
$\boldsymbol{\phi}^{+}$	0.5416	0.2637	0.2676	0.0468	0.1165	0.2613	0.2015	0.2257	0.3552	0.1677	0.1842	0.1942
$\boldsymbol{\phi}^{-}$	0.0525	0.0928	0.0947	0.7074	0.5936	0.0725	0.2134	0.1142	0.0537	0.4373	0.2449	0.1489
$\boldsymbol{\phi}$	0.4891	0.1708	0.1729	-0.6606	-0.4771	0.1888	-0.0119	0.1115	0.3014	-0.2696	-0.0607	0.0453

The positive flow values were used to get the partial ranking (Table 5). According to the PROMETHEE I partial ranking, P-1, P-9, P-3, P-2, and P-6 are the superior ones among the twelve alternatives and P-10, P-5, P-4 and P11 are the alternatives that are found to be inferior to the other alternatives. It should be noted that the PROMETHEE I partial ranking may not help to find the most comprising alternative. Therefore, the complete ranking was determined, which is based on the net flow values given via PROMETHEE II, to identify the most comprising alternative (Table 5).

Table 5. Alternative rankings.

Partial ranking	P-1	P-9	**P-3**	**P-2**	**P-6**	P-8	**P-7**	**P-12**	P-11	P-10	P-5	P-4
Complete ranking	P-1	P-9	**P-6**	**P-3**	**P-2**	P-8	**P-12**	**P-7**	P-11	P-10	P-5	P-4

According to the results of PROMETHEE II, P-1 was selected as the most comprising alternative. The other alternatives are listed in a descending order of their net flow values, also shown in Table 5.

In order to check the validity of the proposed approach and its usability in their company, the opinions of three decision makers, who had the opportunity to utilize the proposed approach, were sought through face-to-face interviews. The decision makers claimed that the proposed approach was a useful and efficient tool, and could be easily used in their company.

4. Conclusion

Project selection is one of the crucial decisions of construction companies. This study aims to propose an integrated approach utilizing the combination of AHP and PROMETHEE methods, which may assist construction companies in selecting their urban renewal projects in a more objective, realistic, and objective way. The proposed approach was applied in a construction company, which predominantly undertakes urban renewal projects in Turkey. The company management found the proposed approach beneficial, easy, efficient, and useful. In future studies, fuzzy numbers can be used when evaluating the qualitative factors.

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Challenges in public facility management: Some remarks to the EN 15221 FM standard

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Abstract

The collective of Standards of EN 15221:2011 refer to the facility management (Facility Management, FM) focusing on the FM as a product and the budget of FM. This standard was created with the aim of unification the operation of business service processes. In the public sphere, while the application of the standards arise as a great challenge, its understanding, and the lessons drawn from it might be important for both the community facility operators and managers. In the article, the Author sets up the model of the public facility management according to the descriptions of the Standard, and highlights the problems and focus points of the public utilization of the Standards by systematic examination of elements and analysis of relating literature. The article, based on the model set up, articulates suggestions for the adopters and the users of the public FM.

Keywords: Facility Management, EN 15221 Standard, Public Organization, SLA, Building Operation

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1. Introduction

At certain fields of real estate industry – no matter how surprising this fact is – there are no public standards; experts work based on inner guidance of professional organisations exclusively. There is only one exception area in real estate industry, that is the facility management (FM), ruled by a public standard. The EN 15221 standard (referred to as the Standard) was started to be composed in 2002 and nowadays has seven sections which were launched between 2006 and 2011, that are obliged to apply in all member countries of the European Union. Even though, because of the overlap of different branches, it is difficult to estimate the volume of the European market of facility management, a study calculated it roughly to 655 billion Euros [1]. A standard describing the operations of this huge market would be determinative in the field of management. At the same time, among the tightly taken profession as well as the targeted companies the standard is less known and still less applied [2, 3]. In an actual market review [4] the interviewed companies, being familiar with the FM as a business branch, criticized the lack of integrated European standards!

The Standard was established for for-profit companies, according to business demands, targeting on the so-called FM product and the relating budget. Keith in his article, prepared for decision making of the standards [5], emphasized the interdisciplinary of the special field of FM and found that in business life, the show up of FM would indirectly have a positive effect on the way of thinking of the public sphere. In our opinion, for non-profit companies and for public users, the collective of EN 15221 Standards bears important edifications and raises important questions at the same time. Some of these questions affect directly the standard, while other questions highlight the problematic focus points of the public facility management. In our article we mention some of these questions.

2. Model of FM, Based on the EN 15221 standard

The seven chapters of the Standard discuss the definitions and description of processes relating to FM on 356 pages. The chapters also discuss the explanations of FM definitions, FM contracts, quality insurance, processes, area measurement and benchmarking. In our opinion, the substance of the group of Standards is best-presented by Table 2 of Issue 4. (See Figure 1).

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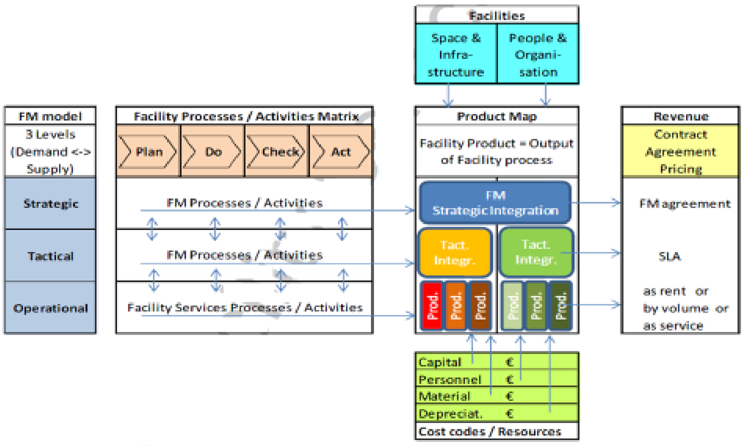

Figure 1: Relationship Model of FM (EN 15221:4.-2011, Fig. No. 2)

In the centre of the table, there can be found the map of products of FM levels with relating costs and revenues. The Standard lists the activities into three main groups such as strategic, tactical and operational activities, while it makes a distinction between the superposing facility processes of planning, doing, checking and acting. The activities of the processes create the FM products and services. The exact description, costs and budgeting of FM products and services can be generally found in the FM agreement, in the SLA (Service Level Agreement). Applying the above point of view, on the below Figure No. 2, we attempted to rearrange the elements to indicate the key problems of public FM and their relationships to each other.

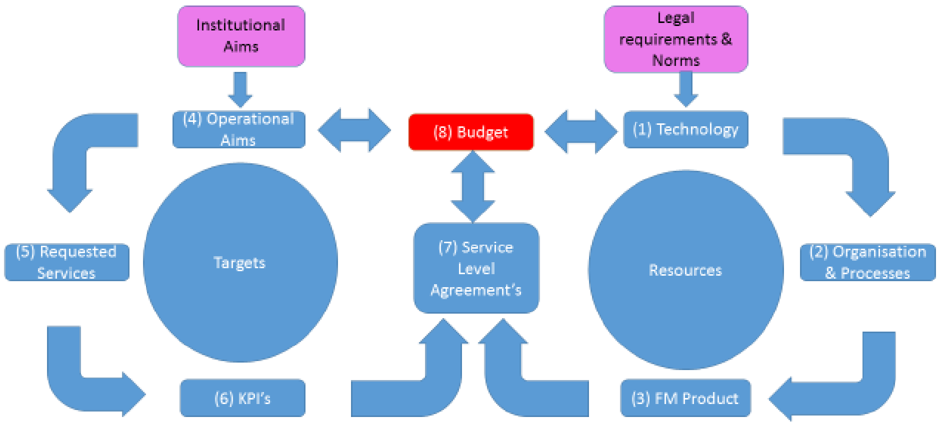

Figure 2: Model of Public FM

In our model with two loops presented in Figure 2, we divided the one-poled standard of EN 15221 focusing exclusively on the resources into two poles; while in the corporate sphere the target system of FM can easily be defined as the main service of main corporate processes, at the same time in the public sector, the target system is complex and varies according to institutions. Therefore, in our opinion, the target system and the resources are to be considered as the two different poles of the public model.

We have to consider two main drivers above the operating cycles, namely, the unity of institutional targets and the consequences determined by the law, rules, regulations and standards. The targets of functioning are derived from the institutional aims. While the general aim (errand) of the institution is independent from operations, the targets of function are already part of the two-loop FM cycle being in a constant interaction of its elements. Another input point of the cycle is the system of legal requirements determining the resources of the real estate and built-in technical specifications. Public real estates are to satisfy all sort of needs to which needs there are countless legal rules and regulations, standards, demands joining, made on habits. The buildings and the built-in technologies might be in compliance on different levels, which can appear in the model as the variables of the FM loop-cycle also. The cycle gets to the determination of costs of the agreement (SLA) on the side of the target system, starting from the principle of creating aims of function, beyond the adjustment of service levels and the relating expected output indicators, while on the side of the resources, from the direction of the processes built on technologies, and from the relating organisation arrive to the description of the product, that becomes the input data of the SLA and the budget. In the following chapters, we will consider one after the other, the elements of the two-cycle loop in view of the Standard and the technical literature; first we will examine the resources, than the targets, and finally, the cross-section of SLA agreements and budget.

3. Resources

3.1. *Built-in Technology*

The FM Standard considers the buildings to be maintained and the built-in technologies as a given facility. The everyday maintenance practice is expressible in differences considering the conditions, facilities, building automation and method of utility of two buildings with similar functions. As these differences are huge, the processes relating to the buildings will be necessarily different. The above is increasingly true in respect of public buildings. On the one hand, the functions might be heavily different (as two office buildings show numerous similarities, a school building and a hospital have nothing common but the differences), and on the other hand, the conditions of the buildings are fluctuating between extreme boundaries. At the same time, in general we can say that the public sphere is frequently suffering from the existence of outdated, unsuitable technologies, and the lack of sources for investments [6].

Even though it would be essential, the facility operators are not involved in the process of planning of the technology, therefore, even in the case of newly built real estates, they cannot be optimally facility managed [7]. The above is confirmed by Benett and his fellow author [8], as examining mathematical models they found that it is more expedient, to outsource the investment and facility management bundled, being a more cost effective solution. **Seeing that the Standard will presumably not deal with the built-in technologies, in this question, we do not see any difference between the private and public utilisation of the Standard.**

3.2. *Organisation & Processes*

The Standard, in its fourth chapter pays special attention to the structure, relation and changes of processes. At the same time, the Standard considers that the setup of the organisation providing the basis and structure of processes are given, supposing that an effective organisation is existing within the company suitable for reaching the business target in the most effective way, and this organisation is also able to manage the FM area too. We can consider it as an aptitude that the public sphere is organised differently from the business sphere, along multidimensional principals therefore its' efficiency, considering it from strictly business standpoint, is worse [9]. It is well-known for example, that the organisational changes become more effective in the private sphere than in the public areas [10]. It is also undoubted that the innovation spreads much more difficult in the public area [6].

Even though the public projects are considered more bound, an actual study [11] indicated that, regardless to the culture, public building projects might function with success, based on the trust of cooperating parties. Jalocha highlights that in the interest of the mentioned multi-dimensional compliance, a project manager working in a public sector ought to have numerous additional competences than a project manager working in market environment [12]. This statement stands for not only one individual but for the whole of an organisation. **All the above mean that the facility management processes of an organisation under public direction should be planned more accurately and prudent than the ones of business entrepreneurs.**

3.3. *The FM Product*

The Standard takes precious good care of defining the certain FM products and services. It is a highly important aspect, since who could interpret the meaning of a unit of cleaning or a unit of supply without this knowledge. The Standard assigns definitions to FM activities habitual in business life, and provides the frame for further definitions of activities. Of course no definitions were made for all diverse public activities, **one of the first exercises for the public user to determine, to circumscribe his own activities according to the methodology given by the Standard.**

4. Targets

4.1. *Operational Aims*

The Standard considers it as an aptitude that the functioning aim is not more than the cost-effective service of the main activity. Even in the classical paper of location analysis [13], it is already mentioned, the difficulties of quantifications of public expectations, therefore the decision-preparation models of private sector cannot be directly applied. The different expectations and intentions might be considered as special “switches” [7], among which the financial effectiveness is only one. Financial effectiveness can be examined with the analysis of the life-cycle costs. The importance of LCC-analysis in public investments is also emphasized in the study of Perera et al, issued by IISD [14], highlighting the fact that this is only one of the possible target values among others for optimisation. The targets and indicators of functioning can be directly derived from the institutional targets by careful analysis [15].

4.2. *Requested Services*

The Standard does not describe nor identify those products, services among the FM products that can be derived from the operational aims. In the public sphere, as it is outlined on Figure No. 2, all services and service levels can be determined based on the operational aims, which are chosen by the user from the well-defined palette of FM products.

4.3. *KPI’s*

The Standard dedicates a separate chapter to measurement of output (EN 15221-7, Benchmarking). Townley in Alberta, Canada, examined 16 museum organisations [16] in the public sphere. He stated that the business type output measurement means only one dimension of rationalism for the community of the museum, while the institutional aims can be interpreted along with different “rationalities”. De Toni [17], while analysing the study case of a huge Italian hospital states that the public FM has two consumers, one of them is the contractual party, being the management of the hospital, and the other is the final consumer, the patient himself. The output valuation of the two consumers is significantly different. This is why De Toni suggests the introduction of the differentiated method called Balanced Scorecard, making it possible, to measure the contentment of both consumers. From the nineties, the public users also started to apply different quality management systems f.e. the TQM. Since then, it is still a difficulty, to unify the ramifying public targets into one quality management model [18]. In respect of the quality, in the international technical literature, it is already a determining opinion that the public sphere, especially the non-profit organisations are able to provide a higher-lever service, since they are not enforced to minimise costs because of profiteering [19]. **To reach the above, however, the operational aims are to be determined, and the services are to be exactly articulated in the interest of choosing the output indicators in the appropriate dimensions and according to the targets.**

4.4. *The Service Agreement (SLA)*

A complete chapter of the Standard is dedicated to the standardised contents of service agreements (EN 15221-2). The contents of the SLA are partly made of the FM products, partly of the expected level of services and also of the relating output measuring indices. The unified form of the agreement and contents is just an illusion in the business life as well; so many law firms, so many forms of agreements, especially considering the public sector. The unwritten law, the inspection bodies, the relating rules and regulations, for example rules of procurement, are different in every institute, in every specialty and in period of time. Bureaucracy is a significant hindrance of quick changes [10]. **The Standard provides an excellent content guideline, the agreement writers in public sphere also should take advantages of it.**

4.5. *Budget*

According to the Standard, the budget is in the centre of the FM relationship model (Figure No. 1). It is true that opposite to the corporate thinking, in public sector, the optimisation of budget is not the sole target [21], this is why it is important to choose the correct “switches” of the target system. Rostás articulates as: the balance of the tangible and intangible profits between the before and after conditions of the public developments are altogether always positive for all affected social and professional groups [22]. At the same time, in public medium, budget used to be tightest bottleneck, therefore it is necessary to place it into the centre of the iteration cycle of the double loop. It derives from the model and the conceptuality of the Standard, that an operational aim based budget has to be prepared for the FM. The budget should contain both the investment and operational costs. Opposite to that, the public sphere is usually applies the base line budget applying the budget modifying the previous budgetary period [20]. The institutional budget, in the focus of the target and toolkit system, expresses and makes links between the aims and the targets with numbers, but only in the case when the contents and activities of the SLAs' are clearly defined. **In public sphere, this can be happen only in case the budget is prepared by the breakdown of activities, to exceed the earlier base approach budgeting practice.**

5. Summary

Even though the FM Standard was made for companies, it also articulates important guidelines for the public sector users as well. We should mention the methodical system of facility management that provides a frame for the FM activities. The Standard offers a methodology for planning processes and defining products; it highlights the necessity to prepare an activity-based budget. For the latter, it is essential, the working out of SLA agreements. Kwak et al [23] while analysing the literature of PPP (Public-Private Partnership) projects, rank the problems of the company and public cooperation into four main groups that are as follows: the competence of the public direction, the choosing of the suitable partner, the appropriate distribution of risks and financial sources among participants. Therefore, the application of SLA agreements according to the Standard should highly contribute, not only within the public sphere, but also within business and public relations, to the improvement of efficiency.

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Innovative Method for Real Estate Valuation Using Data Mining Software

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Abstract

This paper presents an innovative method for real estate valuation. Currently, the most common method of real estate valuation relies on comparisons with similar structures, cost and yield analysis. The innovative method proposed in this paper, called “historical market price”, uses mathematics, statistical and database-founded algorithms for valuation. Input data comes from specialized software which systematically gathers, analyses and valuates data connected with real estate market development. Every six months the database expands by more than 650,000 price offers (advertisements) on purchase or rent of flats, houses, commercial buildings and allotments. This method can be used for valuation of real estate which was purchased previously if rough data is known about the original transaction (especially purchase price). The method suggested in this paper is grounded in true and exact information taken from the last purchase and identifies structural and technical differences in the condition of given real estate, as well as changes in price levels for the given location (street, neighborhood, city, region, etc.). Current valuation methods are not capable of taking into account these historical, yet exact and valuable pieces of information concerning real estate. Current valuation methods are based solely on current data and present state of the real estate market. This approach may be vulnerable to manipulation by either parties of the purchase contract.

Keywords: data mining; property market value; software; statistics; valuation of properties.

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1. Literature review

At present, market value/common price is mostly valuated by comparison with other similar buildings, cost and yield analysis of the real estate. [1]

One of the most common methods for establishing yield are these: calculation of eternal fixed income (constant yield over a long period of time), yield value established by means of appraisal norm, and calculations for variable yield. [2] Valuation of real estate based on yield is also known as capitalization model, as defined in accordance with Executive Order No. 1265 of the Danish Financial Supervisory Authority, Enclosure 8. [3]

Comparative model of real estate valuation is based on comparison of appraised real estate with values of similar kinds of real estate which were sold previously in the same or comparable location. Comparative method comprises both cost value of a construction (acquisition of construction units of a building and its equipment) and possible yields of the given contract (potential rent income). [4]

Valuation model based on costs calculates all current costs needed to re-build the real estate to such state as it is valuated, including costs of allotment purchase. [5] This method appraises the area encompassed by building structures, kind of building, its life-span, current rate of detrition and other parameters. [6]

It is also possible to use different valuation attitudes apart from the ones described above. It may be efficient to use different approaches for specific buildings - for example valuing rental properties using a recursive model. The recursive method is similar to the discounted cash flow method in that it discounts future cash flows, but it differs in that it recognizes that rental income can unexpectedly change in the future and allows rental property owners to adjust to these changes. [7]

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It is also possible to use Mass Appraisal Models and Automated Valuation Models (AVM) for appraisal of mutually comparable buildings. Several valuation methods have been developed for such purposes, namely direct market models and comparable sales models. [8]

Scholarly literature comprises a number of studies dealing with the gathering of data from completed real estate transactions and the valuation of its development as well as predictions for the future real estate market. Let me name a few of them: Reference paper [9] describes a method of about creation of a real property database to determine capitalization rate of real estate. Reference paper [10] presents a method of applying the ensembles of genetic fuzzy systems to build reliable predictive models from a data stream of real estate transactions. Reference paper [11] describes data mining methods of real sales data from an assessment office in a large US city. Reference paper [12] presents a prototype system for real estate information collection and visualization.

2. Historical market price method

Lately, there has been a substantial rise in the number of business transactions which result in a change of real estate ownership. Such situation is allowed by low interest rates in mortgages which stay low even from a long-term point of view. Therefore, mortgages are available to a large proportion of population. Another reason for the rise is the fact that investments in real estate generally carry low risks and high level of legal protection. Real estate is often used as a contract pledge or for different investment purposes, and it is widely considered to be a safe form of investment. Thus, there is often complex documentation for each real estate which tracks and records its life cycle. Such documentation generally involves design drawings (ground plans, section plans, perspectives, spatial arrangement changes), legal documents (insurance contracts, rental contracts, land registry documents, purchase contracts, work contracts, market price valuations, experts' statements), and maintenance-related documents (structure passports, maintenance and replacement plans for individual construction units, invoices for construction work, auditing plans, expert technical inspections, servicing and maintenance activities).

The appraiser gathers all available information concerning the valuated real estate. It will include location in order to establish market value of property. When there is a previous appraisal or purchase contract for that same real estate, the appraiser has a valuable instrument for assessing actual previous market value and current state of appraised property. However, current valuation methods do not allow the appraiser to use such information to its full potential. The appraiser will describe certain information in his current valuation but he has very few tools to use this data for calculation of current market value of real estate. Still, the original purchase price informs the appraiser about objective and concrete value of property at a given date in the past which accounts to its location and in relation to other similar estates. With such data, the appraiser does not work with fuzzy estimates. Instead, it is data connected to an actual purchase which was carried out in the past, and it gives specific details on the conditions which ruled the purchase, i.e. describes real objective market value of real estate. The previous purchase price contains and is influenced by the kind of real estate and its size, construction material characteristics and technical state of building. Also its location, availability of transport to work, scope of services in given location and orientation of real estate in relation to compass points, negative issues of the location, and a number of other important parameters which influence decision-making process of buyers are also included.

If we assume knowledge of change of price level from original to current state in given real estate category and location, we may be able to simply, yet very precisely deduce current real estate value from historical market value. Current market value is governed by this equation:

$$P = P_h * I_d * I_a * I_c \tag{1}$$

Where

P … Current market price.

P_h … Historical market price ascertained from documentation for appraised real estate (previous purchase contract, previous appraisal of value, previous expert statement, etc.).

I_d … Index of detrition in given period of time as determined by dates of previous information of market value and date of appraisal ($I_d \leq 1$).

I_a … Index of constructional and technical augmentation of real estate. It is considered for cases of renovation, reconstruction, extension or superstructure of given real estate within the interval delimited by information of historical value on one side and time of current appraisal on the other side ($I_a \geq 1$).

I_c … Index of price level change in given location and for given category of real estate within the interval delimited by information of historical value on one side and time of current appraisal on the other side.

2.1. *Historical market price of real estate P_h*

Historical market price of real estate P_h is found in documentation of appraised real estate which is ideally provided by the current owner or facility manager. Such information is most readily available in old purchase contracts, old real estate appraisal, expert's statement, or construction contract for a new construction. If none of these documents are available, it is possible to ascertain a copy of acquisition of property document at the local land registry which only charges a small fee for these copies. If no copy or information is available whatsoever, historical valuation method cannot be used for real estate appraisal.

2.2. *Index of detrition I_d*

Index of real estate detrition I_d is calculated by a linear method as the intervals of detrition are short when compared to overall life cycle of a construction. The equation which governs index of detrition is:

$$I_d = 1 - \frac{n}{12 * L} \tag{2}$$

Where

n … Number of months between the dates of information about historical value of real estate and current appraisal.

L … Total expected life-span of appraised real estate (in years).

2.3. *Index of constructional and technical augmentation I_a*

The index of constructional and technical augmentation of real estate I_a is calculated by means of an expert estimate. The index value depends on the scope of construction work realized between the date of the information about historical price and the date of current appraisal. Index values mirror the extent of costs expended on the construction work which led to augmentation of constructional and technical state of real estate. It should not take into account common operation costs, nor costs expended on long-term sustainability of the construction. It is also necessary to bear in mind that every crown/euro expended on construction loses value from the very moment it is used because of the attractiveness of the given location. The loss of value mostly ranges between 50-80 % immediately after installing a new construction unit in a building. The loss can be minimized in case of constructions in historic city centers. The statements above are confirmed by a rule used in the real estate market which suggests that it is economically unfeasible to reconstruct (e.g. a bathroom) if the owner is planning to sell the building.

If no improvement, reconstruction, annex or superstructure was not noted on appraised real estate within given period of time, the index value is considered equal to 1. In case of constructional or technical improvement of real estate, the index value will normally be higher than 1.

2.4. *Index of price level change in given location I_c*

The index of price level change I_c is a key parameter for the historical market price method. The software called EVAL was developed by the author of this new appraisal method to calculate monthly indexes of change in market prices of real estate. It sorts by category of real estate and location.

EVAL is a software application which gathers, analyzes and valuates price offers of real estate as published on real estate servers. The current scope of software application allows for recording most real estate advertisements published online in the Czech Republic. Information from real estate servers is gathered monthly by means of automated mechanisms, and stored in a database. The application has been operating since 2007. To demonstrate the volume of data acquired, in the first half of year 2015, the database has stored 650,000 new records of price offers on real estate purchases or rent - flats, houses, allotments and commercial real estate. The software tool allows for detailed analysis of market price development in time (in monthly periods) in all municipalities in the Czech Republic, and in all common categories of real estate for rent or sale.

The index of price level change in a location I_c is governed by the following equation:

$$I_c = \prod_{i=1}^{n-1} I_i^{kl} \tag{3}$$

Where

I_i^{kl} … Monthly index of market price change given for month *i*, category *k* and location *l*. Index value is calculated by EVAL software by means of development trend in real estate market price.

i … value *i=0* is valid for the month which states information on historical market price of appraised real estate, e.g. if a purchase contract was signed on 15th September 2007, *i=0* is valid for the month of September 2007, *i=1* is valid for October 2007, etc.

n … Number of months between the date of historical price information and current date of real estate appraisal.

*Real estate category **k*** is defined by EVAL when valuating accommodation unit by parameters as follows. Real estate category does not have to be denoted by all parameters, it may be defined by any given combination:

- Space arrangement of the accommodation unit - 1 room + kitchenette (kk), 1 room + 1 kitchen, 2 (rooms) + kk, 2+1, 3+kk, 3+1, 4+kk, 4+1, 5+kk, 5+1, other.
- Ownership - private, housing association, other.
- Kind of building - brick, panel, wood, other.
- Technical state - very good, good, bad, new building, to be reconstructed, newly refurbished.

*Location **l*** is defined by EVAL when ascertaining the value of the accommodation unit. The software uses a set of predefined parameters. Location does not have to be expressed by all of the parameters; it can be defined by any given combination:

- Region - Prague, Central Bohemia, Southern Bohemia, etc.
- Municipality - Beroun, Kladno, etc.
- Street - Jablonova, Americka, Pplk. Sochora, etc.

Historical market price method allows us to calculate price level change in given location I_c, making use of one or several bases for comparison. Several locations and categories may be summed up for comparison if they are applicable to given valuated real estate. The index of price change in certain location I_c is governed by the following equation:

$$I_c = \frac{\sum_{j=1}^{m} I_{cj} * v_j * k_j}{\sum_{j=1}^{m} v_j} \quad (4)$$

Where

I_{cj} … The index of price change in a given location for comparative basis *j*. General calculation of the index for one basis of comparison is designated by the equation (3). Comparative basis represents the same or similar location of a specific category of real estate compared to the real estate which is being valuated.

v_j … Value of comparative basis *j*. This parameter expresses the value of the comparative basis *j* for appraising real estate when contrasted against other comparative bases. For a comparative basis which is defined by the same category and location as the appraised real estate, a comparative basis with the highest value should be used. As the number of categories and locations rises (street → municipality → region), the value of comparative basis will drop.

k_j… Coefficient of adjustment for comparative basis *j*. The coefficient expresses how much better (or worse) a category/location of real estate is than the appraised real estate. For a comparative basis defined by the same category and location as the appraised real estate, the coefficient equals 1.

m … mass (total sum) of comparative bases ($m \geq 1$).

3. Case study

An example of historical market price method is illustrated for better understanding. The following example will show the valuation of accommodation unit with given input data:

Category: flat
Layout: 1 room +1 kitchen
Technical state: good
Address: Jablonova Street, Prague
Ownership: private
Kind of building: brick
Original price: 1 350 000 CZK (price ascertained from original purchase contract signed on 15th September 2007)
Valuation date: 15th November 2015

Figure 1 displays EVAL window for accommodation unit valuation. The user enters the historical purchase price (P_h = 1 350 000 CZK) of the valuated real estate at the beginning of valuation process, and chooses from a range of dates - month in which the historical price was obtained (September 2007) and month of valuation (November 2015). Next the user needs to establish the value of detrition index (I_d = 0,98) and constructional and technical augmentation index (I_a = 1,05). There is no need to establish floorage or usable space of accommodation unit as the flat which is being valuated is exactly the same as in the past.

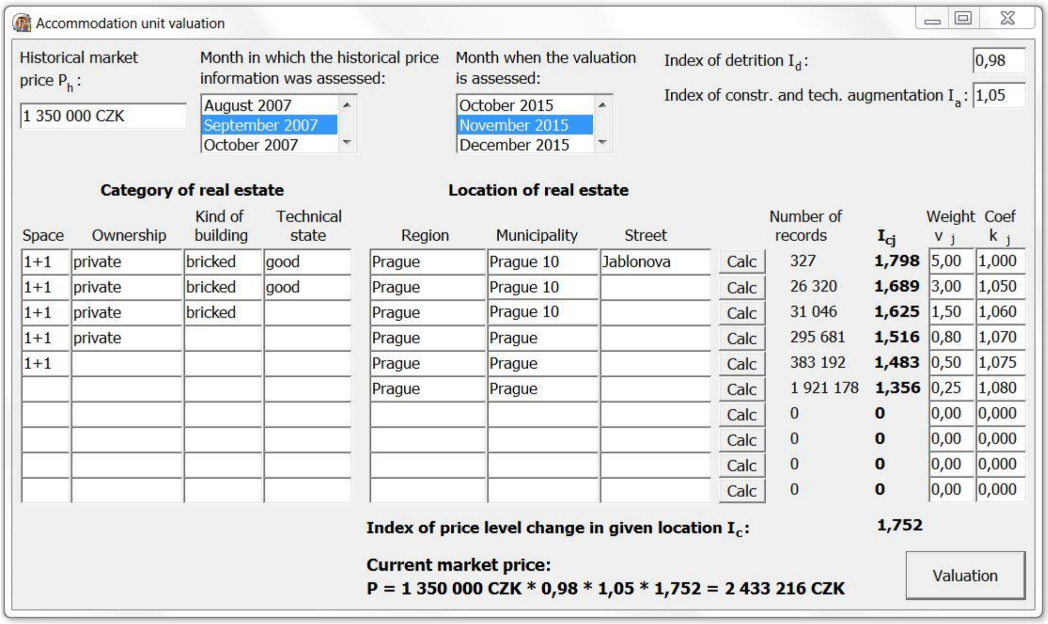

Figure 1 Valuation of a flat using historical market price method.

In the next step of the valuation, the user establishes several comparative bases which the user sets as appropriate for comparison with the valuated unit. For the sake of this demonstration, six comparative bases were chosen.

The first comparative basis usually represents the same category and location of real estate as the valuated unit. The example uses the exact same category and location (layout 1 room + 1 kitchen, private ownership, brick building, good condition, region Prague, municipality Prague 10, street Jablonova). EVAL database holds sufficient number of cases for comparison 327 advertisements. The highest value of comparative basis is considered (v_1 = 5,00), adjustment coefficient k_1 = 1,000.

Other comparative bases are chosen then, usually defined by a higher degree of aggregation, according to appraiser's expert opinion. These comparative bases contain a larger number of data generated from EVAL database (327 → 26 320 → 31 046 → 295 681 → 383 192 → 1 921 178). Higher degree of aggregation leads to less specific results, e.g. leaving out filters for specific street, municipality, kind of building, ownership, etc.

With higher aggregation, comparability of database output with valuated real estate diminishes. Therefore, it is suggested to lower the value of comparative basis v_j as well (5,00 → 3,00 → 1,50 → 0,80 → 0,50 → 0,25). At the same time, it is necessary to adjust coefficient k_j so that differences between compared real estates in various locations and categories are eliminated (1,000 → 1,050 → 1,060 → 1,070 → 1,075 → 1,080).

With this input, EVAL calculates the index of price change level in given location (I_c = 1,752) and then establishes current market price of real estate (P = 2 433 216 CZK).

4. Conclusion

Historical market price method is an innovative approach to valuation of real estate market prices. It is based on the comparative method of valuation combined with mathematic, statistical, and database algorithms. It can be used to establish market value of flats, houses, commercial real estate, and allotments. It can also be used for determining common rent for a flat, house, commercial real estate or allotment, and for establishing market value of real estate to a given date in the past.

The choice of different levels of aggregation and filtering of data makes it possible to use this innovative method even for valuation of atypical real estate or real estate in a location where there is insufficient number of price offers for comparison. Also it can be used where it is difficult to establish objective market price (e.g. small municipalities, borderline regions, allotments detached from commercial centers of regions).

The usefulness of this method is limited by the necessity of having trustworthy data concerning actual purchase prices from previous sale of valuated real estate. It has the advantage of speedy processing of input data about price level in a specific location by drawing directly from EVAL's offline database. The appraiser has more to rely on than his own research of real estate market.

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A Real Option Model to Evaluate Investments in Combined Heat and Power (CHP) Projects

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Abstract

Cogeneration technologies such as Combined Heat and Power (CHP) have promising features for providing the electrical energy that various industries require while reducing emissions and other environmental impacts of these industries. Investments in CHP systems require substantial implementation costs followed by a relatively long period of recovering the invested capital through savings in utilities bills. Appropriate timing of CHP system investments can reduce capital expenses and enhance returns on investments. An appropriate investment valuation method is needed to identify the appropriate time to implement a given CHP system and to find the values of properly scheduled investments. Real options analysis provides the ability to deal with investment timing under uncertainty. Existing real options models have several limitations when it comes to decision making about investments in CHP systems. In this research, some the theoretical limitations of current real options models are overcome. A new real options model to evaluate investment options for CHP systems under uncertainty is created. This model is tailored to the context of investment decision making for cogeneration technologies including CHP systems. The primary contribution of this research to the body of knowledge is the application of a method to estimate the volatility of CHP investments subject to uncertainty; and an investment valuation approach to identifying the best time to implement CHP systems and to determine the investment value. It is expected that this work will contribute to the state of practice by presenting a new valuation tool that help in making hard investment decisions and will therefore increase the likelihood of achieving global sustainability goals.

Keywords: Combined Heat and Power (CHP), Flexibility, Investment Evaluation, Real Option Analysis (ROA), Uncertainty

1. Introduction

Electricity power is vital for economy development. The electricity sector, on the other hand, is one of the largest sources of greenhouse gas (GHG) emission in the world. It is estimated that in the United States 31% of the total GHG emission in 2013 was generated by electricity sector (Department of states 2014). GHG emission has become a universal concern as a key factor contributing to climate change. Concerned about dangerous effects of climate changes, a breakthrough and legally-bonding agreement was signed by 196 countries at the Paris conference in December 2015. The agreement set out a plan to limit global warming to below 2 degrees Celsius by various means including the reduction of GHG emission (Robbins 2016). Increasing energy efficiency in the industry, buildings and transport sectors and reducing the coal-fired power plants are among the main steps suggested in order to reduce the GHG emission (IEA 2015). Cogeneration using Combined Heat and Power (CHP) technology is an approach to generate electricity and useful thermal energy in a single integrated system on site. In a CHP system the wasted heat generated in conventional power generation could be recovered as useful heat power (Chittum and Kaufman 2011). CHP is an efficient way of energy production with many benefits as in the following:

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- Increase the generation efficiency -from 30-35% in traditional power generation systems to 90%- (Rong and lahdelma 2011);
- Decrease the fuel consumption between 10 to 40% (Madlener and Schmid 2003); and
- Reduce the wasted energy in grid which could have a significant impact as in many countries such as United States more than 15% of the generated electrical energy is wasted in grids (EIA 2010).

In spite of the benefits, considerable barriers exist to the development of CHP. Among these barriers is the economic feasibility of investment in CHP systems. Investment in CHP systems often requires a considerable implementation costs with a low-rate return of capital investments over a relatively long time (Kashani et al. 2014). There are many uncertain factors such as installation costs, electricity and natural gas prices that affect the value of investment in CHP systems. Benefits in a CHP system is based on the electricity saving in the system. The natural gas and electricity prices are both subject to uncertainty. These prices are usually estimated based on historical price data. Evidence suggests that generally there are differences between actual and projected energy prices (EIA 2010). Moreover, installation cost of a CHP system is not stable over time. The installation costs are subject to uncertainty but generally expected to decline over time. A tradeoff analysis between electricity saving benefits and implementation costs of CHP system must be conducted to evaluate the economic feasibility of investment in CHP systems. In order to do so, a proper investment valuation approach is needed. Conventional investment valuation methods such as Net Present Value (NPV), Return On Investment (ROI), and Payback Period (PP) (Datta and Kumar 2015, Guo et al.2014) have two major gaps in evaluation of investments under uncertainty including implementation of CHP systems. First, conventional investment valuation methods do not incorporate the uncertainty of key investment factors such as costs of installation, and costs of inputs such as electricity and gas. Second, using the conventional investment valuation methods, the value of flexibility in timing the investment in CHP systems is omitted (Kashani et al. 2014). Current investment valuation methods assume that the investment in CHP could be made only on a now-or-never basis meaning that if the investment is not favorable at present, it should be taken of the list of investment alternatives. Consequently, conventional methods do not recognize the value of investment timing and cannot determine the most appropriate time to invest in projects such as implementation of CHP systems. Nevertheless, in reality an investment could be implemented at point in time when installation cost is lower compared to the present value of energy cost savings. In this paper, a new approach for valuation of investments in CHP systems is proposed. This proposed approach is based on the Real Option theory. It is fine-tuned according to the characteristics of investments in CHP systems. The model considers the uncertainty about energy cost saving benefits resulting from uncertain electricity and natural gas prices as well as the installation costs. This approach could be used as a proper tool to evaluate the CHP systems investment. Utilizing the proposed approach, the optimum installation time can be identified by simulating the CHP systems investment under uncertainty. So, investors could have a better understanding of benefits of CHP systems implementation than conventional methods of evaluating. The rest of this paper is summarized as follows. Section 2 provides a brief overview on state of knowledge in investment valuation approaches. Section 3 describes the proposed real options approach. In Section 4, an illustrative example is provided to highlight the capabilities of the proposed approach. Section 5 provides a brief conclusion on this research.

2. State of Knowledge

The most commonly-used methods of investment valuation are NPV, IRR and PP (Datta and Kumar 2015, Guo et al.2014). Despite the popularity of the abovementioned methods, they have serious limitations in evaluation of combined heat and power generation systems. First, these methods do not incorporate the uncertainty about future energy savings benefits resulted from the implementation of CHP systems. The uncertainty about future energy savings benefits is stemmed from the uncertainty about a variety of factors including future energy demand levels, future electricity prices, and future gas prices. Second, current methods do not consider the value of flexibility in timing the investments. Nevertheless, CHP investments could be implemented at any time in the future when the situations are favorable. Appropriate investment timing can reduce the implementation costs and provide a better capital return (Kashani et al. 2014). Ignoring the flexibility in timing the investment as well as the uncertain factors in CHP investment can lead to the underestimation of investment values. Underestimating the value of investments in CHP systems can lead to the elimination CHP systems as viable alternatives for reducing energy consumptions and GHG emissions. The real options theory is an appropriate alternative valuation method that can be used to overcome these limitations. Real options theory is based on stock option pricing method in finance (Myer 1977). Stock options are contracts sold in the market, giving the buyer the right, but not the obligation to buy or sell a determined amount of stock with a predetermined price (Ammerlaan 2010). Myer (1977) states that the future investment by corporations is comparable to a financial option and could be analyzed likewise. Real option analysis has been used by academics and practitioners for more than 30 years in investment analysis on projects with uncertainty. Fleten and Nasakala (2010) investigated a natural gas power plant investment utilizing real option analysis under the uncertainty of electricity and gas prices. Ashuri et al. (2011) applied the real options theory on solar panel investment under uncertainty. When it comes to the valuation of CHP investments, an appropriate real options approach is needed. This approach should utilize a mechanism to systematically estimate the project volatility as a key factor in project evaluation. This approach should also utilize an appropriate mechanism to identify the optimum time to implement the CHP system. Besides, this approach should provide the risk profile of investment in the CHP systems. Considering the importance of investment in energy systems like CHP, creating more appropriate investment valuation methods is highly important in order to avoid over and under investments. In the rest of this article, a new real options approach for evaluating investments in CHP systems is presented. The proposed model takes into account the uncertainties of investment, provides a risk profile, and determines the optimum implementation time of investment.

3. Methodology

The proposed CHP investment valuation approach, takes into consideration the uncertainty about future electricity and natural gas prices, as well as the variation of CHP system implementation costs over time. Moreover, it provides the risk profile of the investment along with the optimum implementation time. The main steps of our methodology contain:

- Develop a binomial lattice and conduct Mont Carlo simulation in order to characterize the uncertainty about future electricity price
- Simulate scenarios for future natural gas prices
- Develop an experience curve model for the future CHP installation costs
- Identify the optimum investment time
  Develop the risk profile of investment in CHP system

3.1. *Develop a binomial lattice and conduct Mont Carlo simulation in order to characterize the uncertainty about future electricity price*

Implementing a CHP system, leads to energy saving benefits resulted from a reduction in need for electricity provided by the gird. To estimate these benefits, the electricity price should be estimated over the investment horizon. In order to estimate the future price of electricity, a binomial lattice is created (Kashani et al. 2014). A Mont Carlo simulation on the binomial lattice can be conducted in order to characterize future energy price movements and the resulting energy saving benefits over time. The binomial lattice provides a structure on which different random paths of electricity price could be generated in each iteration of the simulation. The binomial lattice defines the probable prices in specified basic period (Δt), for example Δt could be a month or a year. The electricity price (R) at the beginning of each period could be a multiple of u (u>1) for the upward movement or a multiple of d (0<d<1) for the downward movement. The upward and downward movement have different probabilities, p (0<p<1) for upward movement and 1-p (0<1-p<1) for downward movement. This pattern continues period by period until the end of investment horizon (Figure 12). The parameters of u, d and p could be obtained from expected annual growth rate (α) and the annual volatility (σ) of electricity price data –equation 1 to 3- (Kashani et al. 2014). After the creating electricity price lattice, different random paths are generated on this lattice in each iteration of a Monte Carlo. For each electricity price path, the electricity saving benefits can be calculated by multiplying the projected electricity price by the amount of electricity generated by a given CHP system.

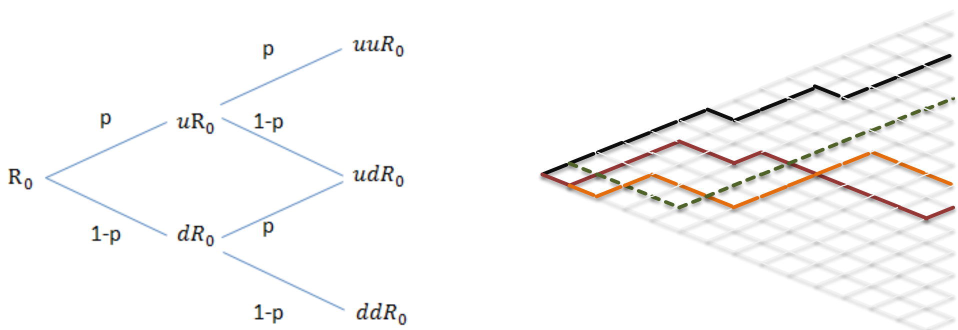


Figure 12: Electricity price binomial lattice (Left) and Random paths on the electricity binomial lattice (Right)

$$u = e^{\sigma\sqrt{\Delta t}} \tag{1}$$

$$d = e^{-\sigma\sqrt{\Delta t}} \tag{2}$$

$$p = \frac{e^{\alpha\Delta t} - d}{u - d} \tag{3}$$

3.2. *Simulate Scenarios for future natural gas price*

In a CHP system the generated heat is used on site for electricity generation purposes. In order to estimate the costs associated with providing required natural gas, the amount of natural gas needed for heating is calculated and multiplied by the estimated natural gas price in each year. In order to estimate the natural gas price, various scenarios can be created. These scenarios are obtained from of reliable models utilized by the academicians and practitioners. By conducting Monte Carlo simulation, scenarios can be randomly picked and energy costs can be calculated.

3.3. *Develop an experience curve model for the future CHP installation costs*

At present, CHP generated energy is relatively more expensive compared to energy provided from conventional sources. However, it is estimated that the implementation cost of CHP systems would decrease over time due to innovation and learning-by-doing effects (de La Tour 2013). The experience curve is a widely used tool in order to characterize the changes in the costs of technologies over time. The experience curve demonstrates that the production cost of a new technology is decreased by accumulation of experience measured by cumulative production. The experience curve is simply demonstrated by the following formula (Weiss 2010; Hartley 2010):

$$P_t = P_0 \cdot Y_t^{-E} \tag{4}$$

Where Pt is the implementation cost at time t. P0 is the price of first unit. Yt is the cumulative production in MW up to year t, and 2-E is progress ratio (PR). PR shows the amount of cost reduction after each doubling of the cumulative production. The estimation of E is based on historical data and expert's opinion. In this article the implementation cost of CHP system is not constant over time and decreased over years using experience curve. The average experience rates for energy supply technologies are often around 20% (Patel and Blok 2013). It means by doubling of cumulative production of CHP systems the implementation cost reduced by 20%.

3.4. *Identify the optimum investment time*

In the proposed approach, the CHP system could be implemented whenever the present value of energy saving benefits exceeds the implementation costs. A minimum electricity price boundary is used to determine the optimal time of investment. This minimum electricity price boundary is developed using the method described in Kashani et al. (2014). The optimum time to invest in the CHP system is whenever the electricity price, for the first time passes the minimum electricity price boundary.

3.5. *Develop the risk profile of investment in CHP system*

The investor’s risk profile is developed using a Mont Carlo simulation. In each iteration, an electricity price and a natural gas price path are randomly generated. Then, using the minimum electricity price boundary, the present value of investment is calculated considering the optimal time for implementing the CHP system. The resulting distribution of present value of investment can be used for investment decision making.

4. Example

An illustrative example is presented to demonstrate the capabilities of the proposed real options approach. In a hospital, the annual average heat and electricity consumption are 56.2 and 12360 MWh. An 800 Mw CHP unit is being considered for this hospital. The implementation cost of this system is estimated to be 1780 $/KW. The maintenance cost of this system is 0.01 $/KWh. The investment horizon is 16 years. The interest rate is 20%.

Using the above information, an analysis was conducted in three parts:

- Economic evaluation with considering the uncertainty of electricity, natural gas price and optimal time of implementation.
- Investment valuation considering the uncertainty about future electricity price
- Investment valuation without considering the associated uncertainties

In the first part, it is assumed that the future electricity and natural gas prices are known and there is no uncertainty about them. Project investment starts in the first year of the investment horizon. Benefits of implementing a CHP system are calculated by multiplying the energy price in any given year by the corresponding amount of energy conserved. Annual energy saving benefits resulting from investing in the CHP system should then be discounted by a proper discount rate. The present value of investment is calculated from the summation of discounted benefits of the system over its life. The present value of CHP investment was calculated to be -565,004.

In the second part, the uncertainty about the future energy prices was characterized using a binomial lattice. Using Mont Carlo simulation a random path of electricity prices across the binomial lattice were generated. A distribution of the present value of investment is developed. The cumulative distribution of present value of investment is shown in Figure 13.

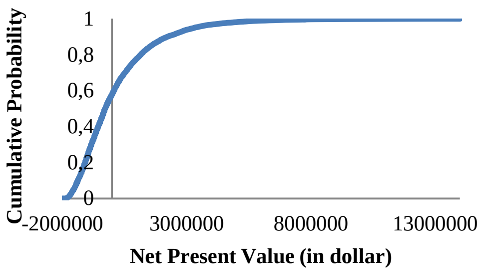
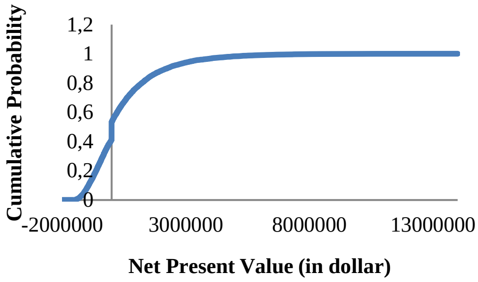


Figure 13: Cumulative probability of NPV with the only uncertainty of electricity price

In the third part, the uncertainty about future electricity prices is characterized as mentioned above. Fives scenarios of future natural gas price are developed *[Ten Different models used in Gas price scenarios: 1. Lift model, 2. CIMS-US (Consolidated Impacts Modeling System) model, 3. US-REGEN (Electric power research institute), 4. Energy 2020 model, 5. Nems (The National Energy Modeling System) model, 6. EPA-IPM(Environmental Protection Agancy)-(Integrated Planning Model), 7. MRN-NEEM (North American Electricity and Environmental Model), 8. US National Markal Model, 9. FACETS model, 10. ADAGE model].* A Monte Carlo was conducted through one scenario was randomly selected randomly in each iteration. The minimum energy price boundary demonstrates the electricity price in each year by which the present value of project equals to zero in that year. So, if electricity price goes becomes less than the minimum energy price boundary in a year, then investment present value get negative in that year. In each iteration, it is checked whether the randomly generated energy price path crosses the minimum energy price boundary. The CHP system installed whenever the energy price path crosses the minimum energy price boundary for the first time. The installation cost of system changes over time in as modeled by the experience curve. In each iteration, the present value investment was calculated. The cumulative distribution of investment value is developed (Figure 14a). Moreover, the probability of implementing the CHP system in any given year over the investment is also developed as shown in Figure 14b.



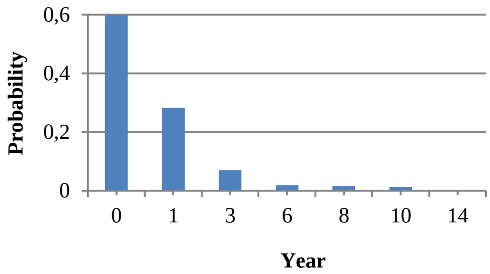


Figure 14: (a) Cumulative probability of NPV in optimum installation year with uncertainty of electricity price, natural gas price and implementation costs(left) (b) probability of implementing the CHP system over the investment horizon (Right)

5. Conclusion

To evaluate investments in CHP system, a proper trade-off analysis should be conducted between energy saving benefits and system costs. The method should have the ability of considering benefit uncertainties such as future electricity prices, natural gas prices and installation costs. Moreover, it should be able to identify the optimum implementation time. In this article, a novel approach for valuation of investment in CHP systems based on the real option theory is presented. This approach identifies the optimum implementation time, based of which the installation cost obtained from an experience curve. The benefits of the system are calculated under uncertainties of electricity and natural gas prices. Utilizing the proposed real options approach can lead to the development of the risk profile of investment in CHP systems. Using this approach, decision makers can have a better understanding of the investment in CHP investments.

Greenhouse gas emission and its contribution to climate change has become a global concern. Increasing the efficiency of energy production and reducing the dependency on fuels are among the main mechanisms suggested in order to reduce the GHG emissions and the global warming effect (IEA 2015). Utilizing CHP systems are among the efficient ways of producing energy. Implementation of CHP systems requires large-scale investments that will be recovered by uncertain energy saving benefits.

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Real Option Application in Energy Performance Contracts

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Abstract

Energy Performance Contracts (EPCs) are mainly designed to facilitate energy saving and greenhouse gas emission reduction. Despite their numerous benefits, EPCs have not been utilized to their full potential. A variety of factors hinder the adoption of EPCs including long time investment, uncertain market, technology and credit and performance risks. These barriers discourage stakeholders and parties to invest in energy sector. Owners and Energy Service Companies (ESCOs) can overcome the barriers to adoption of EPC by making adjustments to current EPC schemes. Flexible design of the contract enables managers and parties of the EPCs to adapt project to circumstances that develop. Improvement on EPC schemes is essential to achieve the success in implementing EPC contracts. Research is needed in order to identify and evaluate various approaches to improve current EPC schemes. This study proposes the incorporation of real options in order to enhance the flexibility in EPCs and thus, encourage ESCOs and investors to participate in energy efficiency and saving endeavors. The real options approach incorporates a learning model, such that management makes better and more informed strategic decisions when some levels of uncertainty are resolved through the passage of time. This study focuses on two conventional types of EPCs, Guaranteed Saving (GS) and Shared Saving (SS). As part of this study, option to expand that can be incorporated in EPCs is identified. In addition, the opportunity to embed this option in two main contract types is explored. Various scenarios are considered, and the challenges and benefits of incorporating each option are evaluated. The findings of this study enhance the understanding about the possibility of incorporating real options into EPC contracts in order to increase the investment value for various projects stakeholders.

Keywords: Sustainability, Real option, Energy Performance Contract (EPC), Flexibility, Energy Efficiency

1. Introduction

Advancing energy efficiency can lead to more efficient use of final energy or useful energy in industry, services, agriculture, households, transportation, and other areas. It provides the greatest potential for moderating the energy demand. This is critical since, in many situations, it is more cost-effective to invest in end-use energy efficiency improvement than in increasing energy supply to satisfy demand for energy services. Efficiency improvement can also have a positive effect on energy security, local and regional air pollution abatement, and employment[1, 2] Therefore, energy efficiency is considered a critical aspect of efforts to achieve the ambitious goal of realizing sustainable development. Nevertheless, there are several barriers to enhance energy efficiency including the issues concerning institutional and legal frameworks, financial and economic incentives, and information, knowledge and technology gaps (International Development Finance Club Promoting Energy Efficiency 2013).

Energy Performance Contracts (EPCs) can provide a cost-effective route to overcome barriers to energy efficiency. Energy Performance Contracts, provided by Energy Service Companies (ESCOs), are novel market mechanisms to finance capital improvement that allow funding energy upgrades from cost reductions. Under an EPC arrangement an external organization (ESCO) implements a project to deliver energy efficiency. The stream of income from the cost savings repays the costs of the project, including the costs of the investment.

Performance-based contracts have been essential to the growth of the energy efficiency industry[3]. In fact, EPCs have become the most important mode for developing the energy service industry [4]. However, evidence suggests that EPCs have not been used to their full potential[5]. A significant barrier to the application of EPCs is the uncertainty associated with these contracts. Credit and performance risks often impact the outcome of energy efficiency investments. [6]. The development of the ESCO industry to its full potential is also inhibited by the difficulties of negotiation a balanced contract between the owner and ESCO[7]. Appropriate contract schemes are required in order to promote investment in the field of energy performance contracting.

To maximize the value of EPCs, parties to these contracts must devise plans to strategically manage uncertainty. EPCs must be enhanced in order to facilitate appropriate allocation of risks among the involved parties and allow them to deal with various situations as various uncertainties evolve. Owners and ESCOs can incorporate proactive flexibility in the form of real options into their investment decisions, and enhance opportunities to optimize the performance of their investment. This can result in well-structured EPCs that enable fair sharing of benefits and risks, offer a win-win situation for owners and ESCOs, encourage adoption of energy efficiency measures [8].

The objective of this paper is to explore the opportunity for embedding real options, option to expand only, into EPCs and thus, add more flexibility to these contracts. To achieve this objective, the working mechanism of expansion option is characterized and the opportunities to embed it in EPCs are evaluated. The remainder of this paper is organized as follows. Section 2 provides an introduction to EPCs and the risk allocation to the ESCOs and owners. Section 3 presents an introduction of the basic principle of the real options theory. Section 4, explains the methodology used in this study for evaluation and implementation of options in EPCs. Section 5, identifies option to expand the project that can be incorporate in EPCs. The applicability of this option type and the type of EPCs that best fit a given option type are also discussed in this section. Section 6 concludes the paper presenting the main findings and some perspective for further research.

2. EPCs and risk allocation

Energy Performance Contracts (EPCs) are alternatives to the conventional Energy Efficiency (EE) contracts implemented by energy service companies (ESCOs). The existing EPC models differ in the way that risks are hedged by involved parties including the owner, ESCO and lender [9]. Generally, there are two types of risks in EPCs: credit risks and performance risks[10]. Credit risks are related to the financing of the project and the party in charge of financing bears this risk accordingly. On the other hand, the performance risks are very diverse; from the uncertainty in energy price to energy audit quality and people factors.[6] Performance contracting is essentially a mechanism to transfer energy efficiency performance risks from the owner to the ESCO[6]. Therefore, the ESCO always bears the performance risks.[11]

EPCs are divided into two major contractual forms: Shared Saving models and Guaranteed Saving models. In a shared savings contract, the ESCO shares the value of energy savings resulted from the implementation of the proposed Energy Conservation Measures (ECMs) with the project owner under a pre-determined arrangement that is dependent on project-specific factors. In a shared saving contract, the ESCO typically secures financing from a third-party entity. Consequently both parties bear some degree of credit and performance risk.[12, 13]

In a guaranteed saving contract, the ESCO guarantees the owner a certain level of energy savings resulted from the implementation of the proposed ECM. In case the actual energy savings are less than the guaranteed level, the ESCO would compensate the owner for the difference. The owner is usually responsible for providing required funds from its own internal resources or a third party e.g. a bank or financial institution [10] This contractual form has a significantly different risk profile compared to shared savings. It removes the burden of financial risks from the ESCO. Nevertheless, the performance guarantee must be designed in a way that ensure the recovery of various costs including debt service, Measurement and Verification (M&V) fees to the ESCO, maintenance obligations or other incremental costs stipulated by the contract [14].

When using any of the above-mentioned EPC models, owners and ESCOs are often exposed to substantial downside risks. Incorporating mechanisms that can enhance the flexibility to reduce exposure to downside risks and match the schedule of project savings cash flows can provide potentially great strategic benefits and enhance the value EPCs for owners and ESCOs. Flexibility allows investors to perform more effectively in a world of substantial price and demand uncertainty, and product variety.[15] Real options can be utilized in order to optimally manage the creation and use of flexibility as a device to exploit uncertainty.

3. Basic Principle of Real Options Theory

The term “real options” was coined by Stewart Myers in 1977. He argued that the value of a firm includes the real assets in place plus the present value of options to make further investments in the future. These future investment opportunities are undertaken at the discretion of the firm, just as options on trade are exercised only when it is profitable to do so[15].

Real options are inspired by the financial option that is the right but not the obligation, to take an action in the future. In finance, according to Black and Scholes, "An option is a security giving the right to buy or sell an asset"[16]. When options ideas are used in business and real projects rather than stocks and financial markets, they are called real options. Application of real options analysis is numerous. For instance, a financial assessment under uncertainty may be required in order to determine whether and when the investment should be implemented. Real Options Analysis properly meets this objective[17].

4. Research Methodology

Since the determination of significant potential benefits precedes the effort to fully explore and quantify the value of contracts and options, this study reflects an exploratory effort to characterize the potential benefits of real options in EPCs. The two basic forms of financial options are *"call"* and *"put"* options: A *call* option gives the holder the right but not the obligation to buy an asset at a specified "*strike*" price, within a given timescale. [18]. A *put* option gives the holder the right but not the obligation to sell an asset at a specified "*strike*" price, within a given timescale. [18]. The opportunity to invest can be seen as a call option, involving the right to acquire an asset for a specified price (investment outlay) at some future time.[19] The abandonment option resembles a put option on stock. It gives the option owner the right to leave the project if the project does not meet the expectation in profitability.[19]

The scope of this research includes the characterization of real options applicable to EPCs. Five main steps were followed in the study: 1) Analysis of available literature on EPCs and ESCOs, their mechanism, uncertainty inherent in energy sector and the risk pattern parties confront in different types of EPCs; 2) Analysis of available literature on Real Options and their capability for enhancing managerial flexibility; 3) Analysis of literature on the application of real options in energy investments; 4) Identification of options that have the potential to be embedded in EPCs; 5) Evaluation of the identified options, in this paper only option to expand the project is analyzed, to determine their applicability in dominant types of EPCs. The focus of this article will be the contract terms level including only a quality-based analysis of potential real options in EPCs. The outcomes of this research are as follows:

1. Identify the risk bearer in Shared Saving and Guaranteed Savings Contracts.
2. Develop a framework for potential options to be embedded in different types of EPCs.
3. Define the proposed time for exercising the options
4. Investigate alternative scenarios for option holder (ESCO or Client)

5. Real Options and EPCs

Here the project is built with capacity in excess of the required level so the owner can expand the project when intended [18]. Management then has the right but not the obligation to expand – i.e. exercise the option – should conditions turn out to be favorable. A project with the option to expand will cost more to establish, the excess being the option premium, but may worth more than the same without the possibility of expansion. This is equivalent to a call option.[18]

In guaranteed saving EPCs, where the client is responsible for financing, whether himself or by a third-party, it is rational that the client holds the option instead of the ESCO. One should consider since one of the major risk of guaranteed saving contracts is the level of guaranteed energy for ESCO, it should be considered in the option's terms to set a new level of guaranteed energy in case of exercising the option.

In this situation, it is important to consider the ways that the ESCO can be incentivized by the owner to accept this option and its associated burden. As mentioned before, this option is worth to exercise only when the profit is higher than expectations. This cannot be achieved unless the saved energy passes the guaranteed level. On the other hand, it is one of the key terms of the guaranteed saving contracts to share the excess saved energy profits among ESCO and owner. That means in the case of exercising the option, the ESCO can have its own share from excess energy saving. ESCO can accept the risk of reaching to the new guaranteed level of energy saved amount again after exercising. Thus, there are two possible solutions for incentivizing ESCO: 1) Higher option premium paid by the owner to the ESCO. 2) Increasing the amount of share of ESCO or setting a fixed payment in case of exceeding the new guaranteed level.

There are barriers to utilizing the option to expand in the guaranteed saving contracts. Suppose that the ESCO has the option to expand. Since the credit risk and financing should be done by the owner, whenever the ESCO decide to exercise the option the owner is obliged to finance the project whether is willing or there may be better opportunity in other fields. What comes to mind is an alternative that is inspired by the variable contract term. There can be a shift in the type of financing as the ESCO decide to exercise the option and instead the share of saving will be increased. There is no such option in the typical contracts but it can be implemented as the parties agree on the option.

In Shared Saving EPCs, the ESCO bears both performance and credit risk. Since the ESCO is responsible for financing the project, it is more rational to own the option to expand. The case of exercising is similar to the guaranteed saving.

As it was illustrated in the case of guaranteed saving contracts, the party that bears the credit risk is more likely to be interested in holding the option to expand the project. In the shared saving contracts, the ESCO bears the credit risk. Therefore, the scenario in which the owner holds the option is unlikely. However, in these situations similar to the guaranteed saving contracts, appropriate mechanism can be devised to incentivize the opposite party to become and stay involved in the project.

For shared saving contracts in which energy price is the main factor of profitability of a project, a boundary or threshold for energy prices, which spans the investment horizon, can be identified. (For a detailed discussion on the way to identify the exercise boundary for an option please refer to Kashani et al(2015)[20])

In Figure.1 the cumulative energy saved pattern is shown. At the early stages, the energy saved will raise faster as at the end of the project this increase will happen in a lower rate due to a variety of factors that degrade the performance of a system. [17]

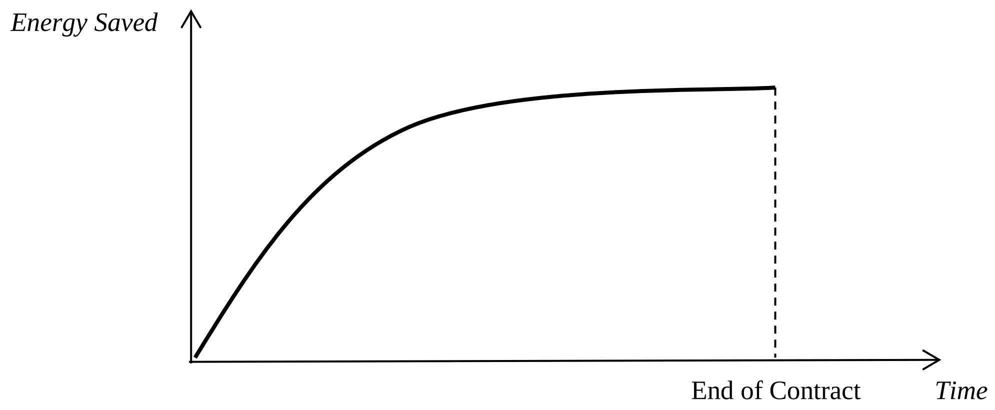

Figure.1- The Energy Saved Pattern

The expansion of the project is justified if higher profits and better prospects are expected as a result of the investment. This is possible when, considering the abovementioned energy saved pattern, the energy price increases over time and, as a result, the amount of saving (Energy saved * Energy price) increase. The boundary identifies the minimum prices at given point of time over the investment horizon at which the value of exercising the option is higher than the value of delaying it exercise. This exercise boundary is shown schematically in Figure.2

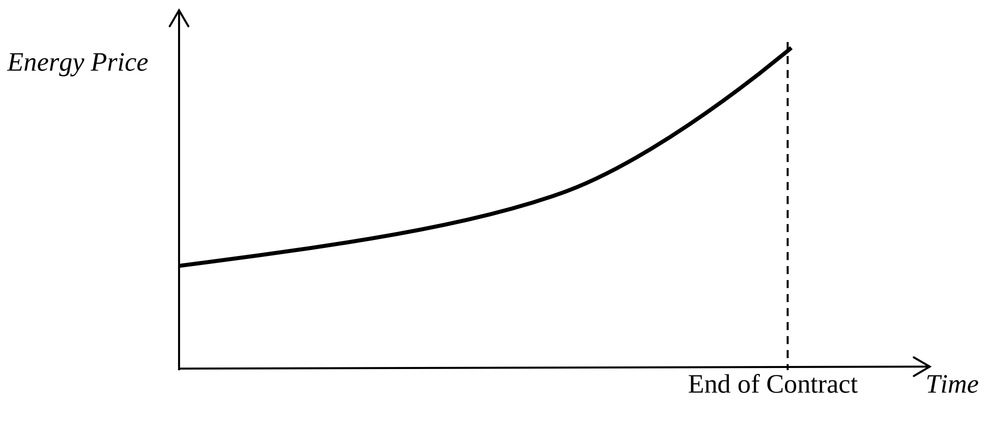

Figure2. - Minimum energy price threshold for option to expand the project

Unlike shared savings contracts, in the guaranteed saving contracts, the level of guaranteed energy saved is stipulated in the contract as the main defining characteristic of the contract. Therefore, for this type of contracts, a threshold for the level of guaranteed energy saved in going to be shaped as shown in Figure.3. As it can be seen, at the end of the contract higher level is expected since the time for recovering the investment is less than before. It is obvious that the level of guaranteed saved energy must be higher than the initial level of the contract at each point since it is the logic of the option to expand.

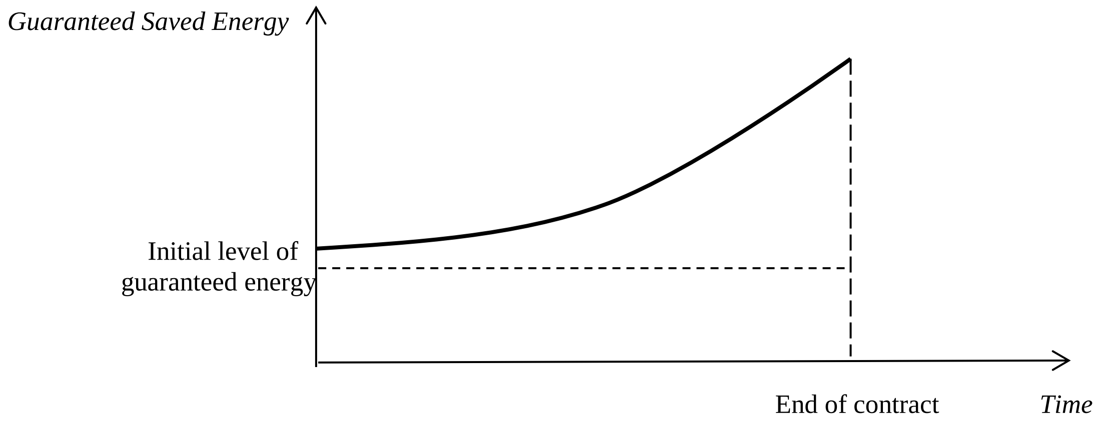

Figure.3- Minimum energy guaranteed level in GS for option to expand the project

Conclusion and future work

Incorporating flexibility in the EPC contracts can lead to more adoption of these contracts and facilitate energy saving approaches. Given the increasing scale of investments in sustainable retrofitting, it is of great importance to put additional terms in EPCs in order to make them more flexible for parties and thus encourage them to use these contracts. The energy based projects due to their high initial costs, high financial and performance risks and uncertainties, caused by their natural source variability, discourage investors to participate in these projects. Embedding real options in EPCs can work as a support mechanism to enhance the value of energy efficiency investments. In this paper, after discussing the risks of EPCs, the option to expand and the opportunities for embedding this option in contract terms were analyzed. The option holder and scenarios for exercising the option was analyzed and at the end the boundary and threshold for energy price and level of guaranteed energy saved was proposed.

A number of extensions to the present work are recommended. A method for evaluation of real options performance and the use of proposed methods such as ROV can be studied in future works. The authors are currently conducting a risk analysis and evaluation method including conventional and real option theory to develop a framework for EPCs.

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Market Penetration and the Incentives of Residential Solar Electricity in the United States

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Abstract

This paper studies the market penetration of residential photovoltaic (PV) electricity generation in the United States. The federal government and many of the state governments of the U.S. are motivated to reduce dependence on fossil fuel technology and reduce greenhouse gas emissions. Photovoltaic systems on the commercial and residential scale have been touted as part of the solution to the problem. One obstacle to adoption, is that residential PV systems have not yet reached a *cost per installed watt of capacity* equal to that of utility power companies in the U.S. Therefore, state governments and utilities are using economic incentives to drive adoption. In this research, a survey was undertaken of available incentives and compared to available data on solar installations per state in the U.S. The result of this comparison showed a strong correlation between the states with the most generous subsidies and the highest number of residential PV systems installed per capita. It appears that economic incentives and energy costs are the two main drivers of residential PV system adoption in the U.S.

Keywords: incentives, net metering, photovoltaic, residential, solar.

1. Introduction

Grid-connected solar energy has tripled in the period of from 2000 to 2008. Solar is poised for further explosive growth due in part to falling costs, government and utility incentives and environmental concern though the technology still represents a small fraction of the total installed capacity [1,2]. Solar energy does not exist in the vacuum and the technology competes with many other forms of electrical power generation. In fact, solar accounted for only 0.22% of the electrical power generation in United States in 2013. The top three sources that year were coal at 38.44%, natural gas at 27.66% and nuclear at 19.18% [3].

The primary question a user a solar must answer is, *How much of the available electricity can be converted to electricity in my location*? Five fundamental factors have the greatest impact on PV system output and they are geographic location, shading, tilt angle and orientation, materials and technology of the PV panel and efficiency of the non-PV components [1].

1.1. *Geographic Location*

High levels of sunlight are critical to the productivity of PV systems. The further from the equator a location is, the less sunlight yearly it will receive. Data has been collected the National Renewable Energy Laboratory for the U.S. Department of Energy to determine the best locations for PV system. Figure 1 is an illustration of the results. The redder an area is, the higher the solar irradiance level is and a higher likelihood of good solar energy production. From the figure, the Southeastern and Southwestern portion of the country appear to be prime candidates for solar technology. The blue and green areas are at the lower end of the solar irradiance levels. The Northeast and Alaska fall into these areas. Solar irradiance is the amount of energy from sunlight per a given area per a given time [4]. A homeowner interested in solar unfortunately has little ability to change his or her geographic location.

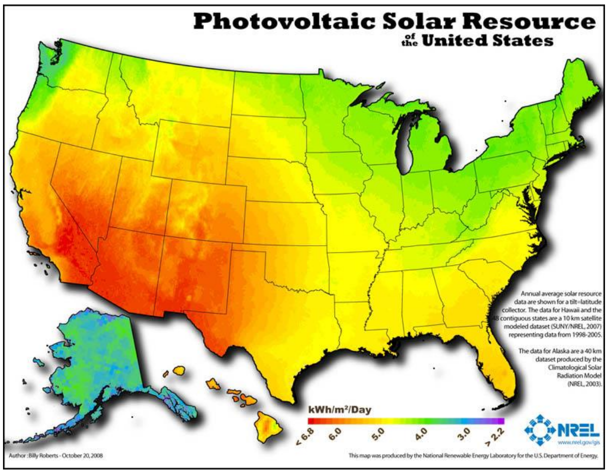

Figure 1. Photovoltaic Solar Resources of the United States [5]

1.2. *Shading, Tilt Angle and Orientation*

A PV panel output is extremely susceptible to shading. A PV panel may lose up to 80% of its output if shaded by a leafless branch. A survey of possible sources of shade should be undertaken to identify any potential sources of shade and a site selected to minimize shade on the PV panels between 9am and 3pm [6]. In the northern hemisphere, southern exposure maximizes PV output. A fixed tilt angle of 15 degrees maximizes year round output. If tilt angle is adjustable, a tilt angle of latitude minus 15 degrees with favor in summer and latitude plus 15 degrees will favor in winter. PV systems are often retrofits on existing structures and an optimum orientation and tilt angle may not be achievable [6].

2. Data Analysis

2.1. *Top Ten States for Solar Potential*

The top ten states for solar potential are listed below in Table 1. These states are known for long, sunny summers and mild winters. They are also located at the far southern regions of the United States closest to the equator. The listing was created from the same data used to create the Photovoltaic Solar Resource map previously seen in Figure 1. States with large land areas in the red to yellow range of Figure 1 are present at the top of the rankings in Table 1.

Table 1. Top Ten States of Solar Potential [7]

1. Nevada 2. Arizona 3. New Mexico 4. California 5. Colorado 6. Texas 7. Oklahoma 8. Wyoming 9. Florida 10. Kansas

2.2. *Top Ten States for Solar Installation Capacity*

The top ten states for solar installation by MW capacity are located below in Table 3. The installed capacities, commercial and residential, were totaled and the States ranked. It would be logical to assume the states with the highest potential solar capacity would also the states with the highest installed capacity. This is not the case according to the National Renewable Energy Laboratory (NREL.) In fact, many states located in the Northeastern region of the United States are present in the top ten. Each state in the Table 2 not present in Table 1 has the ranking for solar potential next to the name. Four of the top ten states in Table 2 are states that rank in the bottom half of states for solar potential. Logically, there must be factors other than potential that drives solar technology adoption.

Table 3. Top Ten States for Solar Installation Capacity [8]

1. California 2. New Jersey (Potential #41) 3. Arizona 4. Massachusetts (Potential #32) 5. Nevada 6. Texas 7. New York (Potential #34) 8. Pennsylvania (Potential #35) 9. New Mexico 10. Colorado

2.3. *Top Ten States for Capacity Installed per Capita*

Since the States are not equal in land area or equal in population, the total installed capacity is a flawed metric in understanding solar technology penetration. Dividing the total installed capacity by the population of each state created the rankings in Table 3. A majority of the states in Table 2 are present in Table 3. Five of the top ten states in Table 3 fall into the lower half of solar potential rankings. Vermont and Connecticut are notable for being nearly at the bottom of the potential rankings.

Table 3. Top Ten States Capacity Installed per Capita [9]

1. California 2. Arizona 3. New Jersey (Potential #39) 4. Nevada 5. New Mexico 6. Delaware (Potential #29) 7. Massachusetts (Potential #32) 8. Vermont (Potential #44) 9. Connecticut (Potential #41) 10. Colorado

2.4. *Top Ten States for Installations per Capita*

The total capacity per state metric includes the sum residential, commercial, industrial and utility scale installations. This makes the metric difficult to use to judge the adoption of solar technology by the residential consumer. Residential, commercial, and utility-scale solar capacity account for approximately 29% each of installed solar capacity. Industrial installations account for approximately 13% of the installed capacity. (EIA, 2012) NREL researchers have collected data on the number of solar installations per state. Making the assumption residential solar systems are installed with the fraction of capacity of commercial and utility scale projects it is assumed residential installations make a bulk of the number of installations. The ranking below in Table 4 were created by dividing the number of installations per state by the populations of the states. The rankings give a good indication of the states with the highest per capital residential installations. Once again, many states rated low for potential are located in the top ten ranking. Factors other than solar potential must be driving adoption of residential solar.

Table 4. Top Ten States Installations per Capita [8]

1. California 2. Arizona 3. Delaware 4. New Jersey (Potential #39) 5. Vermont (Potential #44) 6. Massachusetts (Potential #32) 7. Connecticut (Potential #41) 8. Wisconsin (Potential #40) 9. New Mexico 10. New Hampshire (Potential #33)

3. Incentives, Financing and Tax Credits

PV systems are incentivized by several tax credits and rebates on the federal, state and utility level. Private individuals interested in residential solar must carefully study the available rebates before committing to construction. The North Carolina Clean Energy Technology Center at North Carolina State University has developed "the most comprehensive source of information on incentives and polices that support renewable and energy efficiency in the United States [10]. This effort is financially supported by the United States Department of Energy and can be found at www.dsireusa.org.

The Federal ITC credit currently available to home PV system installations was established by the Energy Policy Act of 2005 (P.L. 109-58.) The law has undergone several revisions, extensions and tweaks but the most recent revisions for home PV systems is found in the Emergency Economic Stabilization Act of 2008 (P.L. 110-343.) Under this law, owners of home PV systems can deduct up to 30% of the cost of installations with no limits for systems installed after January 1, 2009. Homeowners subject to the alternative minimum tax (AMT) now qualify for this credit [11].

Several states offer tax credits and rebates similar to the structure of the Federal ITC. Often these programs are more limited in the dollar amount of the tax credits available and are more restrictive on who may participate. The State of New York offers 25% of installed system cost capped at $5000 and limited to 10kW or small installed systems [1]. Utility incentive programs availably vary between states. Many programs are structured as rebate programs. Utility customers receive cash up front for installation of PV systems. Other incentives programs are structures as performance based incentives (PBI) that pay rebates based on actual generation of PV electricity [1].

3.1. *Net Metering*

Net metering is defined as " a service to an electric consumer under which electric energy generated by that electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period" (Energy Policy Act of 2005). Net metering was first developed in the early 1980s as a way to promote the growth of privately owned renewable energy generating facilities such as solar and wind [12]. This arrangement allows the customer *bank* excess power generated onsite in the grid and tap the grid when generations onsite does not meet demand, thus solving the critical issue with the variable nature of power generation of wind and solar for the private customer. The customer is also compensated for electricity set back into the grid. Net metering policy is set at the state level and varies by a few key metrics.

3.2. *Established Policy*

The first metric is whether or not a state has an established statewide net metering policy. Alabama, Mississippi, South Dakota and Tennessee are the four states do not have established statewide net metering policies. Federal law requires net metering by request but in these states customers have to negotiate one-on-one with their utility [13]. States have implemented varies caps on the subscriber limit as percent of peak. West Virginia's 0.5% subscriber limit is amongst the lowest the country while many states such as Arizona and Colorado have no such limits. When a subscriber cap is reached, no new residential solar customers will be able to register for net metering. Since net metering is an integral component to the economic viability to residential solar, caps may ultimately put the halt to further installation of PV systems [14].

3.3. *Power Limit, Monthly Rollover and Annual Compensation*

States have also elected to place limits on the installed capacity allowed per customer. Arizona limits customer capacity to 125% of connected load while Connecticut limits capacity to 2000kW. Colorado and Connecticut are two of group of states with no set limit. Capacity limits can also vary by utility type, customer type, technology, and system type. For instance, Georgia limits residential solar systems to 10kW while commercial systems are limited to 100kW [15]. Many customers are able to generate a net positive amount of electricity in a given monthly billing cycle. Customers receive billing credits for this excess power and nearly all states allow customers to "rollover" bill credits from one month to the next. North Dakota is a lone exception to this policy and reconciles credits at the end of each billing cycle. Credits are awarded at either the retail rate of electricity or the avoided-cost rate. Avoided-cost is the wholesale or cost of electricity to the utility. States vary if credits are allowed to rollover indefinitely or are reconciled at the end of each billing year. Customers of some states, such as Colorado, are given to choice to rollover indefinitely or to receive a check from the utility for unused credits at the end of each year. Policies can vary between utilities within each state so research is necessary when calculating economic benefits of PV systems [14].

3.4. *Financing/Leasing*

The Federal Government has historically utilized Fannie Mae and Freddie Mac to allow homebuyers to roll into home mortgages to cost of residential PV systems [16]. Today, private financing is growing rapidly in popularity to amongst residential customers to make PV systems more affordable. Two popular forms of third party financing exist: power purchasing agreements (PPAs) and solar leases. In the PPA arrangement, a third party installs a PV system on the residences and the installing company retains ownership of the PV system. Power is sold at an agreed rate (often lower than the utility) to the residential customer. This business arrangement requires no outlay of capital from the homeowners [17]. Twenty-four states allow for third-party PPAs but five have banned their use [18]. Home customers can also enter into leasing arrangements with PV system installers. In this arrangement, a homeowner owes a monthly lease payment to the installation company. Little or no upfront cost to the homeowner can be negotiated [17]. Ideally, the benefit of the solar energy generated and any tax credits will be greater than the monthly lease payment.

3.5. *Non-Financial Motivations*

It is often cited that concern for the environment and reducing greenhouse gas emissions is a common reason for installing solar panels. (CITE 1st Light) President Obama in 2015 ordered cuts in Federal greenhouse gas emissions by 40% partly increasing the use of renewable energy by 40% from sources such a solar and wind [19]. Researchers at Yale and University of Connecticut have found a different motivation for residential solar customers: green envy. The researchers claim that a new installation on a home of a PV system 6 months prior will increase the average installations by 0.44 in a one half mile radius. Within a one-mile and a one to four mile radius installations will increase by 0.39 and 0.12 respectively. Researchers also failed to find nearly as much influence from other socioeconomic and demographic factors such as income, political party registration and the unemployment rate [20,21].

3.6. *Breakeven Analysis*

The key economic metrics to the prospective residential PV system owner is the price per installed watt of capacity that the system will break even in a 30-year system life. Any cost per watt below this price will equal a net positive benefit for the residential customer. NREL, using their System Advisor Model (SAM), has computed this per watt dollar value for Q4 of 2012. Figure 2 below is the graphical representation of the results. It should be noted the reported cost per watt for residential PV systems competed in 2013 was \$4.69/W (\$4.62/W 2012.) [22].

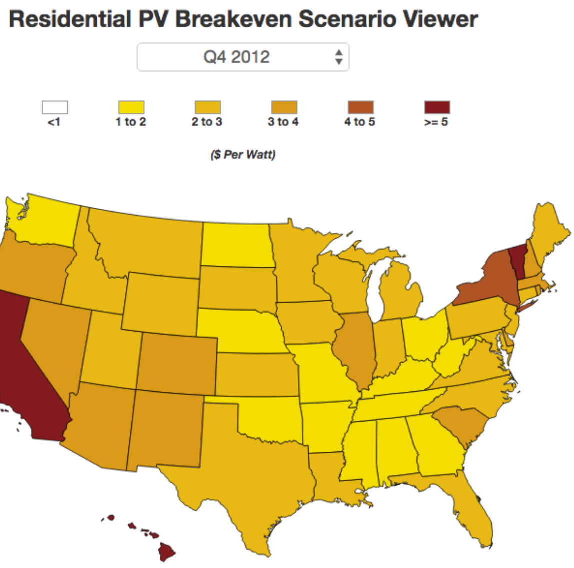

Figure 2 Residential PV Breakeven Scenario Viewer [23]

The 10 most expensive states for electricity are included in Table 5 for comparison to earlier tables. Many of the same states that rank at the top of PV system installs are states with the most expensive electricity.

Table 5. Top Ten States for Most Expensive Electricity per kWh [24]

1. New York 2. Connecticut 3. New Hampshire 4. New Jersey 5. Vermont 6. Maine 7. California 8. Rhode Island 9. Massachusetts 10. Delaware

4. Conclusion and Future Research

It appears that economic incentives and energy costs are the two main drivers of residential PV system adoption in the U.S. States with high potential for solar generation have either ignored or, in some cases, purposefully hampered adoption. Conservative and liberal groups in Florida have joined forces to roll back state laws and regulations they have seen as hampering solar deployment [25]. Future research is warranted to determine the economic effectiveness and efficiency of incentives in driving residential PV system adoption. Government money is not unlimited and it would behoove those governments to implement the most effective dollar-for-dollar incentives.

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Bridge Maintenance Automation

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Abstract

The investment maintenance of valuable buildings is nowadays performed continuously and by means of automated technologies and softwarized construction business systems organizations. For the purpose of the sustainability of traffic and buildings, the automation of technologies requires a matching automation of works- performing systems logistics within business operations as a whole. However, besides the information flow softwarizing, there are as well technological and organizational novelties aimed at the rationalization of the activities. Namely, the technological novelties are new machines-robots-and the organizational ones are the new formulae-the equations of procedures. Thus the vector methods provide for the fulfillment of investment supported by the scientific procedures that are in turn to contribute to the upgrading of indices to show the economic quality of not only a particular company but of state institutions as well. In other words, the aforementioned automation processes provide the possibilities for further scientific research and the development of society.

Keywords: investment, technology, organization, management, robot, software, vector norm, vector organization

1. Investment Maintenance of Bridges – introduction

An investment is an important factor both in constructing new buildings and in maintaining the already existing ones. An investment is observed as either direct placement of funds or as a continuous maintenance activity aimed at bringing a building back to function. Maintenance, i.e. increasing the longevity of buildings, as well as of all functional needs in the life of a man, is very important because of the rational activities of the human society that is in turn achieved by means of iterating investment system consisting of four phases, from conception to maintenance. (Fig. 1).

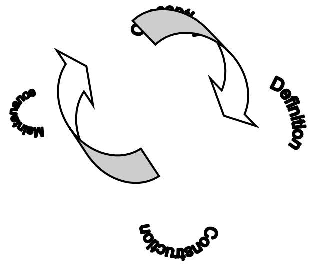


Fig 1. Iteration cycle with the investment phases cycle

It is especially so when the traffic buildings-bridges are concerned as the most important buildings connecting land stretches, or, precisely, road portions. The value of these buildings is always measured in millions of any currency so any society has to be extremely rational when the maintenance of bridges is implied. In these activities, besides political decisions, science has to take part as well as the main force to develop productive powers, i.e. to enhance the development of a society and a state.

In layman‘s terms, maintenance and reconstruction are said to be more expensive than the construction of a new building.

However, a continuous replacement of rapidly-dilapidated construction elements saves the main constructive elements from dilapidation thus decreasing the costs and providing for a longer time of use of a building and for the return of investments. (Fig. 2).

Fig. 2. Bridges in the Republic of Croatia

2. New Bridge Maintenance Technologies

Each construction activity is production. Production is a function of technology and organization (Eq. 1).

$$Production = f(T,O) \tag{1}$$

Each improvement in the organizational or the investment cycle is an important component of the profitability of an investment. Each one of the investment phases can contribute to the rationalization process and there is a special stress on the in situ dimension, i.e. a site or a building is inspected at the scene and this is what gives a spur to the new technologies and organizational elements. The maintenance of bridges in the Republic of Croatia is performed by the state-of-the-art technology, namely the modern hydrodemolition technology which, applied through Conjet robots and high-pressure pumps (Fig. 3), accelerates the investment cycle.

Fig. 3. Hydrodemolition of bridge plates by Conjet robots

3. New Bridge Maintenance Organizations

As organizations lag behind technology (Fig. 4), the tendency is to upgrade organizations so that they develop arm-to-arm with technology, i.e. arm-to-arm with the machinery.

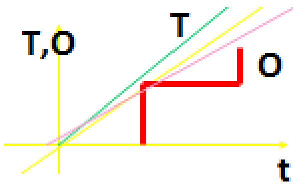


Fig. 4.The relation of production functions

The only way of achieving the aforeomentioned task is upgrading organizations to the level of technology by means of applied mathematics [1], i.e. turning static organizations into dynamic ones (Fig. 5).

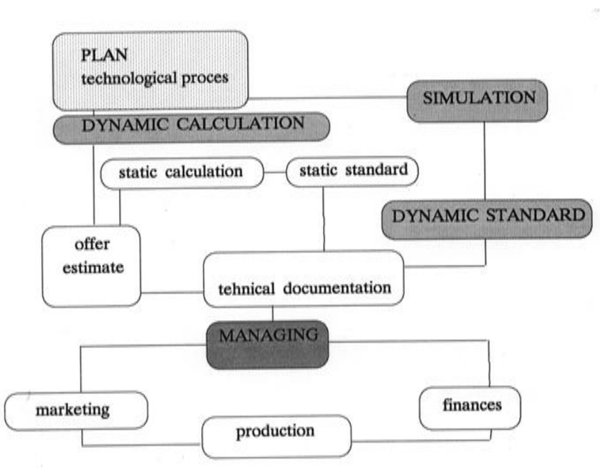


Fig 5 . Dynamic management of a programmed construction organization

A static norm is turned into a dynamic one by means of discovering new vector norms for the implied Conjet robots (Fig. 6) and other technologies as well. It thus turns the deterministic tabular shape of the static norms into the dynamic functional equations shown in the vector space [2].

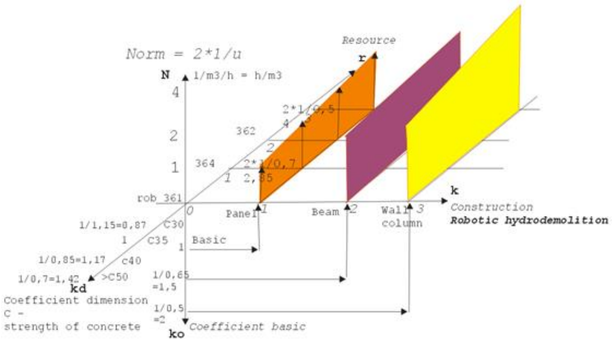
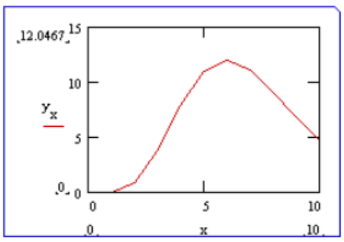


Fig 6. Vector norm of robotic hydrodemolition

The study of hydrodemolition works lead to the description of works by the Erlang distribution equations (Fig. 7) and equations (2) [3].



$$E(y_x) = \frac{k+1}{\lambda}; y_x = \lambda \frac{(\lambda x)^k}{k!} e^{-\lambda x} \tag{2}$$

Fig. 7 the Erlang distribution of the work of Conjet robot

The equation of the vector norm (3) for Conjet robots was derived from the analysis of the hand-written data on monitoring the work of robots on the scene and from the analysis of the existing static norms for various other works *[5]*.

$$N_{k,r,ko_i,kd} = n_r \cdot 1/U_{k,r,ko_k,kd} = n_r / kd_c ko_k Uo_{k,r} \tag{3}$$

The very creation of the dynamic norms implies the creation of the dynamic calculations and this in turns brings a fully mathematical generation of offers by the management system of a construction company.

4. Bridge Maintenance Automation

Besides upgrading the works norm for the automation of the complex process as a whole, a reconstruction of a company’s structure is needed as well so that the business system itself leads to the automation of work and integrated information systems (IIS) are the right solution for this task.

The creation of such system intended for construction (Fig. 8) yielded the preconditions for establishing a vector norm organization of the structure of a company [4, 5].

Fig 8 . IIS of a construction company with the vector structure

However, what has taken care for automation of works is the contemporary Internet digital technology which the GPS technology [6] has appeared and it converts the hand-written data into automated gathering and sending of field-data to the central data processing units within an IIS company system (Fig. 9).

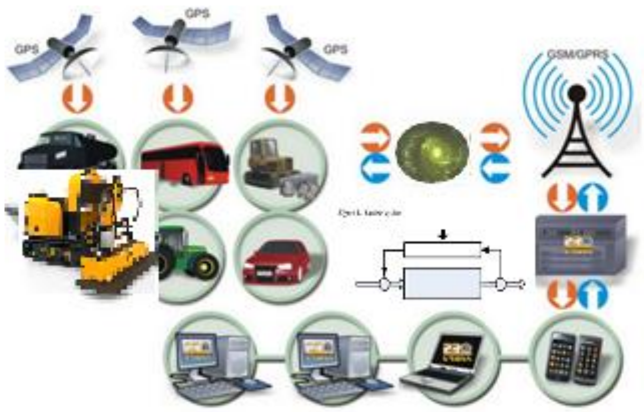


Fig 9. GPS system

5. Conclusion

Optimal investment maintenance of bridges is a result of new technologies and organizations. For this result to be simulated as well, the science of operational investigations is deployed in order to bring the respective costs to a minimum. The study of respective methods resulted in an enhanced combinatory method of planning combined with inscription equations with and without recurring and channels with and without the same dimensions (Equation 3) [7].

$$k_i = k$$

$$K = U\left[\begin{matrix} n_1 \to k_{\max} - 1 \\ n_{\max} \end{matrix} U\left[\begin{matrix} n_2 \to 1 \\ n_1 - k_i \end{matrix} U\left[\begin{matrix} n_i \to n_i + 1, n_k - 1 \\ n_1 - k_i \end{matrix} U\left[\begin{matrix} n_k \to n_1 + 1 \\ n_{\max} \end{matrix}\right]\right]\right]\right] \tag{3}$$

For the purpose of a full automation, the combinatory system regulation via the GPS technology (Fig. 10) is to be subjected to further investigation.

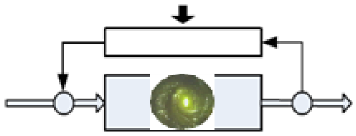


Fig. 10. System regulation

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Conflict Scenario Typologies in a Public Construction Project

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Abstract

Conflicts have critical effects on cost and scheduling in public projects. Due to their complexity and larger scale, public projects frequently cause a high-level conflict that can lead to cancellation. Furthermore, because most of these projects are mega-projects, economic losses caused by the conflict can be enormous. Although investigations into the causes of conflict and resolution have been conducted, their findings have not been applied to conflict solution. This paper aims to establish a conflict scenario of projects based on the causes of conflict and to suggest a mitigation strategy. Representative public projects in which the conflict has peaked are studied, and the conflict scenario is classified by the causes of the conflict. While the aspect of conflict change can be readily identified, the conflict scenario has to be distinguished by the results of the conflict aspect. In this research, five types of conflict scenarios are defined in accordance with the results of completed projects, and characteristics of the scenarios are investigated. The characteristics can be a key factor in finding solutions for conflicts. This research is expected to assist project stakeholders in developing effective strategies for addressing possible conflict.

Keywords: Conflict; Conflict Management; Conflict Scenario; Public Project

1. Introduction

1.1. *Research background*

As public construction projects become larger, they are reaching into the mega-project size. Accordingly, the stakeholder structure has become more complex, and many conflicts occur in the construction project. The conflict involved in public projects affects project performance, including duration and cost, and may result in project cancellation. For projects that are larger and more complex, finding the cause of and a solution to the conflict can be more difficult [1]. Moreover, the conflict occurring in a large project has an important effect on not only project performance but also social governance [2]. Although the government and local jurisdictions continue their efforts to resolve conflicts [3], for example, through the analysis of conflict effects in the project planning phase, conflict occurrence continues to increase.

To manage a conflict effectively, the conflict needs to be recognized and systematized alternatives should be suggested using a fundamental approach. There have been many academic studies to resolve conflicts in construction projects, in particular the social sciences have addressed a conflict occurrence mechanism. The conflict occurs due to differences in stakeholder positions [4, 5]. Therefore, evaluating stakeholder satisfaction is one way to resolve the conflict [6], and stakeholder interest is also important [7]. When a conflict occurs, determining how to respond is also one aspect of the conflict [8]. In engineering science, the schedule or cost management is usually studied [9- 11]; however, analyzing a schedule delay and suggesting a conflict resolution using a mathematical model can provide an alternative but cannot provide a reason in the early stage for the cause of the conflict. Therefore, early evaluation and alternative deduction should be the goal. To address this problem, this research aims to establish a conflict scenario of projects based on the causes of conflict and to evaluate the characteristics of the conflict scenario to identify mitigation measures.

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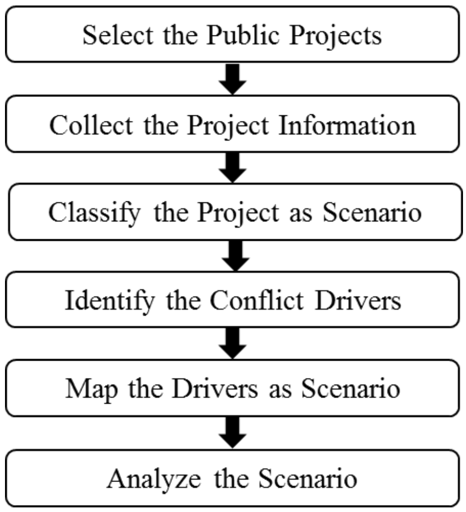
1.2. *Research scope and process*

For analyzing the progression of conflicts, retrospective case studies are used and conflict scenarios are mapped. The research flow is shown in Figure 1. First, public construction projects are selected based on their social effect and the ease of data collection. Then, the data are collected in the form of secondary data from journals, government reports, and other sources. The projects are classified into scenarios based on the conflict impact to the construction stage, and conflict drivers are identified and mapped. The characteristics of the conflict drivers are then investigated to suggest an appropriate strategy for the conflicts.

The most important consideration is the stakeholders, who can be classified into two categories [4, 5]: 1) internal stakeholders who are bound by a contact between the demand side and supply side and 2) external stakeholders who consist of public sectors and private sectors. In this paper, only external stakeholders are considered in the conflict scenarios due to dealing with superficial conflicts.

Figure 1. Research process.



2. Research methodology

2.1. *Retrospective case studies*

Retrospective case studies were conducted for classifying the conflict scenarios. Using retrospective case studies is a method for deducting the meaningful results from a case study through inductive inference [12]. This methodology can investigate a social phenomenon in depth so that conflict cause and effect, progression, and consequences are identified. Moreover, a conflict that may be difficult to analyze quantitatively can be understood by processing data using this method.

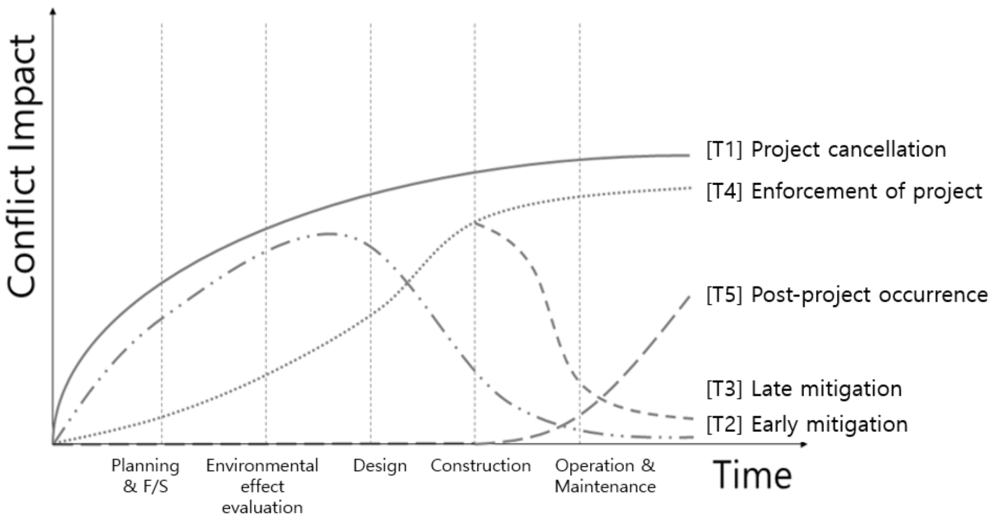
For the retrospective case studies, we selected 22 public construction projects. Project selection considered the social effect, which helps to analyze conflict progression, and ease of data collection since project information, the reason for construction, and conflict aspects are important considerations. Data were collected from journals and government reports to convert unstructured qualitative data from structured information. Insufficient data were complemented through cross-checking against newspapers and private reports.

Table 1. Cases for the five scenarios

Scenario	Case
Project cancellation	Yeongwol dam project
	Ulsan memorial park project
	Anmyeon Island radioactive waste disposal facility project
	Wi Island radioactive waste disposal facility project
	Yongsan redevelopment project
	Gadeok Island airport project
Early mitigation	Cheonggye stream restoration project
	Guri-Pocheon expressway project
	Songsan green city borrow pit project
Late mitigation	Mountain Cheonseong tunnel project
	Mountain Sapae tunnel project
	Saemangeum reclamation project
	Sihwa-Banwol industrial complex project
	Busan memorial park project
Enforcement of project	Miryang transmission line project
	Jeju naval base project
	Iksan waste disposal facility
	Jucjeon-Bundang road project
Post-project occurrence	Onsan industrial complex project
	Yeosu industrial complex project
	Suwon world cup stadium project
	Gori nuclear power plant project

Of the five scenarios listed in Table 1, project cancellation is for cases when severe conflict occurs in the planning and feasibility study stage. Early mitigation represents cases when there is a proper response to a conflict at an early stage. Cases in late mitigation are the most common; due to the continuance of conflict, the cost and duration of a project increases, but adequate compromise results in advancing to completion. Enforcement of a project is when the government enforces the project on the condition of no compromise. Post-project occurrence is for cases when the conflict occurs in the operation and maintenance stage; maintenance cost and usage fees are the main causes of conflict.

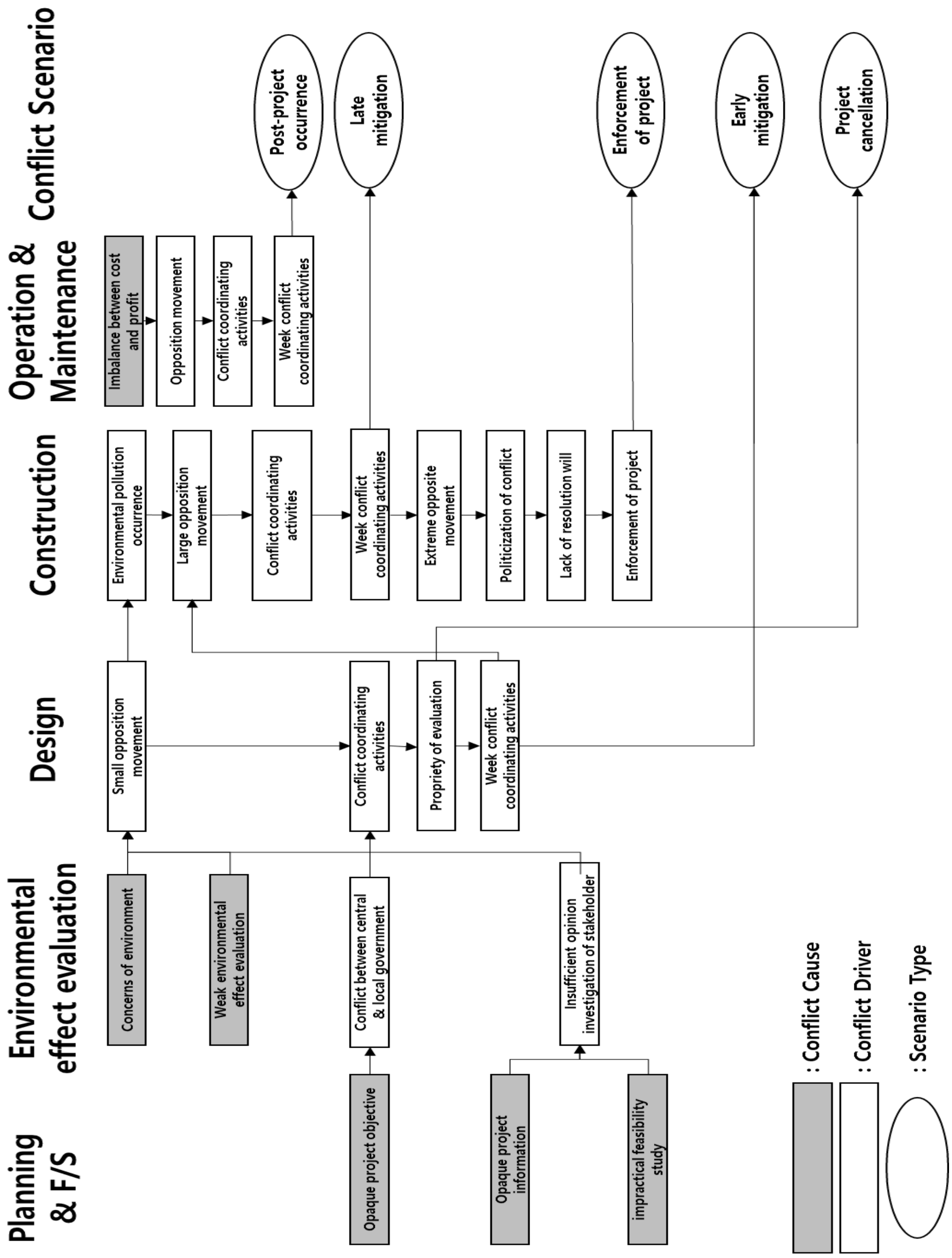
Figure 2. Five scenarios of public construction projects.



2.2. *Path diagram mapping*

To develop the conflict scenario, understanding the progression of the conflict and mapping the conflict drivers are needed. The conflict drivers are deduced and structured by the five project stages, which are 1) planning and feasibility; 2) environmental effect; 3) design; 4) construction; 5) operation and maintenance. For consistency of terms, we combined synonym and analogous terms as representative terms. In so doing, the conflict driver pool was composed to map the scenarios. The conflict drivers were mapped to show the progression of the conflict from the planning & feasibility study stage to the operation & maintenance stage. In Figure 3, the conflict cause is shown to be situated at an early stage (planning & feasibility study stage, environmental effect evaluation), and the conflict deepens at the construction stage.

Figure 3. Conflict scenario map.



3. Conflict scenario typology

Christopher (1986) classified conflict into five types—1) value conflict, 2) relationship conflict, 3) interest conflict, 4) data conflict, and 5) structural conflict—and recorded the characteristics of each types [13]. Value conflict is caused by different ideas, values, and philosophy, and this is most challenging of conflicts. Relationship conflict is caused by strong emotions, misperceptions, or stereotypes. This type can also be affected by other types.

Interest conflict is caused by competition for profit, resources, or rights. Land compensation, NIMBY (Not In My Back Yard), or PIMFY (Please In My Front Yard) phenomena occur due to interest conflicts. Data conflict is caused by a lack of information, while the structural conflict is caused by unequal power, for example, the central government versus local government.

Table 2. Major causes and characteristics of conflict scenarios

Conflict Scenario	Conflict type	Conflict cause	Characteristics
Project cancellation	Value conflict	Poor project feasibility study	Conflict occurrence and deepening in early stage
	Relationship conflict	Distrust of government for closed administration	Unconditional opposition movement
Early mitigation	Interest conflict	Release of information	Conflict occurrence and mitigation in early stage
	Data conflict	Consultation of compensation	Securing transparency and reliability of information
			Active conflict management of government
Late mitigation	Value conflict	Selection of location	Conflict occurrence in early stage and deepening in construction stage
	Data conflict	Compensation	
			Conflict mitigation through reconsideration of project feasibility, technical review
Enforcement of project	Value conflict	Selection of location	Conflict occurrence in early stage and deepening in construction stage
	Interest conflict	Compensation	
			Enforcement of project through armed crackdown, governmental authority
			Continuous conflict after completion
Post-project occurrence	Interest conflict	Environmental issue	Conflict occurrence in operation and maintenance stage
	Structural conflict	Right of facility	
			Local-level conflict between local government and resident

The five conflict scenarios can be matched to the five conflict types. Project cancellation is matched to the value and relationship conflict; a poor project feasibility study or selection of location is the main conflict cause, and an unconditional opposition movement leads to project cancellation. Early mitigation is the solution scenario that mitigates the conflict. The government makes an effort to gain trust, show transparency through a public hearing, and coordinate conflicting activities. Late mitigation and enforcement of a project increase costs and duration delays. Selection of a location and compensation are the most common causes. A conflict that occurs in an early stage is amplified in the construction stage; with a deepening conflict, it becomes a political issue. These two scenarios need to resolve the problem before a conflict reaches its peak. The post-project occurrence has two causes, profit and complaints about rights and environmental issues.

4. Conclusion

In this research, we classified conflict in public construction projects into five scenarios according to the conflict impact to project stages, and we analyzed the major causes and characteristics of the conflict types. Most causes of conflict start at an early stage (planning & feasibility study) and deepen in construction. The feasibility study, environmental issues, selection of location, and compensation are the most common causes of conflict. Most importantly, efforts need to resolve the conflict at early stage.

The classified scenarios can be used to develop resolutions of conflict in public construction projects, particularly with the characteristics of each scenario. In further research, conflict impact will be analyzed by quantitative methods, and a concrete solution will be developed for each scenario.

Acknowledgments

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Foreign Market Entry: An Analysis of Barriers and Market Entry Modes Adopted by Pakistani Contractors

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Abstract

The construction industry plays critical role in the economic opulence of any country. Though developed country contractors occupy major share in the international markets, a number of developing country contractors are increasing expanding their overseas operations. There has been very little variety of work regarding the international market entry modes adopted by these contractors and barriers faced by them while expanding overseas. The aim of this paper is to explore the markets ventured by Pakistani international contractors and to analyze the market entry modes and critical external and internal barriers faced by these contractors. The data was collected by using questionnaire survey method. The findings of the study showed that the surveyed contractors have major presence in UAE and Saudi Arabia. Also, it shows that inaccessible market information is identified as critical external barriers, whereas start-up cost and communication issues are identified as internal critical barriers faced by these contractors. Furthermore, study shows that the two important market entry modes adopted by Pakistani contractors for expanding overseas are Subcontracting and Joint Venture.

Keywords: Internationalization, Barriers, Market entry modes, Contractors, Developing Country

1. Introduction

Different researches done by many scholars have proved that the internationalization of service firms has remained largely under-researched area [1]. As a result, the understanding of this area is less compared to the understanding of the internationalization of manufacturing firms. In spite of the fact that services have been increasingly traded across borders, less scholastic attention has been paid to the internationalization of services firms from emerging economies.

Previous studies have recognized three basic market entry strategies, which are the market selection, entry mode choice and entry timing decision [2]. Furthermore, [3] outlined some market entry strategies which include, choosing a specific market, setting objectives and goals, overcoming barriers, determining a control system to monitor performance, marketing plan to penetrate the market and also choosing the right entry mode to penetrate the market. Selection of the right entry mode for international expansion is a key managerial decision and can have significant and far-reaching consequences for a firm's performance and survival [4]. It is one of the significant parts of a firm's foreign investment strategy. It is inferred that the methods of international market entry vary in three major aspects: (a) cost as resource commitment; (b) control as level of ownership; and (c) risk related to the level of resources committed and the complexity of the environment entered [5].

According to the previous literature, there is still a lack of framework to guide the construction firms to adopt effective entry mode strategies. Hence, this study particularly analyzes the market selection choice, entry barriers and entry mode choices by the Pakistani construction firms in venturing the international markets. The results will be significant for local firms in developing their strategies to face the inevitable foreign market players. Domestic firms will be encouraged and facilitated to expand their business by encountering barriers and implementing effective entry modes to undertake construction projects in international market.

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2. Literature Review

Research has regularly shown that adopting suitable market entry strategies is critical in the firms' decision to enter and later continue in international market. Therefore, before selecting suitable market entry strategies, it is suggested to have an extensive environmental scanning, determination of strengths and weaknesses of the firms and matching international market opportunities and threats with the firms' capabilities [6]. Various researchers have suggested different plans in making the right combination of market entry strategies related to entry mode and entry timing in the international business [7].

The previous researches on the barriers of internationalization have distinguished several extensive areas as market oriented (both international and domestic markets), managerial and industry oriented. It is conceded that barriers of internationalization are present at every stage of the internationalization process. These barriers can vary in intensity counting on the stage of internationalization of the specific firm.

[8] clearly stated the importance of choosing the right entry mode as it requires great resource commitment which may lead to financial burden and time loss. Entry mode is an institutional agreement for organizing and conducting international business transaction or in other words, a decision on how to enter the market. Though, each entry mode comes with its own benefits and risks. Therefore, the decision on which entry mode to be selected is most critical decision faced by MNEs and depends on the internal factors related to the firms' strengths and weaknesses. Similarly, there are external factors related to the international market environment affecting the entry mode choices such as, the opportunities and threats.

[9] have formed a hierarchical model of the basic entry mode choices which are strategic alliance, build-operate-transfer/equity project, joint venture project, representative office, licensing, local agent, Joint Venture Company, sole venture company and branch office/company under two main categories: equity and non-equity. Many researchers have shown that entry mode strategic decisions such as joint venture, wholly owned, and merger and acquisition, are found to be effective entry mode strategies in the international market [10].

Previous studies have shown that choosing a suitable entry mode is critical in order to ensure the performance of projects [10]. [11] asserted that entry mode choices are usually influenced by the internal and external factors such as the firm and market factors. [10] further emphasized that the entry mode plays a significant role in firms' profit making and sustainable growth. Therefore, [12] suggested an extensive environmental scanning, determination of opportunities and threats, and the matching them with the firm strengths for the selection of suitable entry mode. However, there are not much studies that suggest a framework to guide the construction firms in order to decide which entry mode strategies; namely equity and non-equity modes to be used in international market expansion.

3. Research methodology

3.1. *Quantitative - survey questionnaire*

In order to collect primary data for this study, a structured questionnaire was developed to collect data from the targeted sample group, i.e. contractors that are based in Pakistan and have operations in countries abroad. A total of 7 randomly selected contractors were interviewed to pre-test the questionnaire and make necessary amendments or respond to recommended contents [13]. A revised version of the questionnaire was completed after rephrasing ambiguous questions. Respondents were asked a series of questions, derived from the literature, relating to the foreign market choice, barriers and entry mode strategy of their firm in the international market.

The questionnaire was divided into three parts and 23 questions. The company background was included in the first part (3 items), and the second part inquired the respondents on the involvement of their companies towards international activities (5 items). Both of these sections were measured by open end questions. The third part of the questionnaire comprised of questions on barriers their company has faced when internationalizing (9 items). The fourth section of the questionnaire comprised of questions relating to the market entry mode their firm has chosen for venturing international markets (6 items). The respondents were required to state their agreement/disagreement on statements on a 5-point Likert scale with 1 = strongly disagree, 5 = strongly agree. Finally, the collected data were processed and analyzed using SPSS software.

Questionnaires were directed through postal mail, electronic mail and followed-up by telephone calls. A questionnaire was sent to the 126 identified contractors listed in the PEC 2011/2012 Directory, of which 84 firms responded, representing a response rate of 67%. The remaining responses could not be received, either because there was a change in e-mail addresses, business address or telephone numbers.

3.2. *Qualitative – interviews*

To get a better overall understanding of the barriers and entry mode behavior of Pakistani international contractors, in-depth interviews with seven key executives in seven contractors firms were also conducted. To ensure that important matters were not missed, an 'interview guide' was used. The respondents were asked to freely express their opinions related to the issues discussed. All of the interviewed respondents (ranging from CEOs, Directors, senior managers and other executives) claimed to have an in-depth knowledge of their firm's international operations and investments and there seemed to be no reason to doubt their veracity. Each interview took between 60 to 90 minutes, and were digitally recorded, carefully listened and transcribed in written form.

3.3. *Triangulation approach*

A triangulation approach was adopted which aided the researchers to integrate the quantitative results (i.e., questionnaire surveys) with the results from the qualitative method (i.e., interviews).

4. Findings and Discussion

The data in Table 1, from the investigated contractors in terms of firm's legal status, age and overseas experience, shows that the investigated contractors were having mixed characteristics. Seventy six of the investigated contractors (90%) were privately registered while the remaining eight contractors (10%) were publicly listed. Largely, Pakistani construction industry is dominated by the private sector. The investigated firms were possessing specialization in various fields including (1) building and civil, (2) electrical and mechanical and (3) petrochemical. Majority of the contractors (38%) possessed multiple specializations. Major amount of firms (50%) were having more than 20 years age since establishment. Concerning international experience, contractors have diverse nature as around 40% of the contractors have less than 5 years of international experience.

Table 1 Characteristics of the surveyed contractors

Characteristics	Frequency	Percentage
Respondent's designation		
Top management	64	76
Middle management	20	24
Firm's legal status		
Public listed	8	10
Private limited	76	90
Specialization		
Building and Civil	23	27
Electrical and Mechanical	16	19
Petrochemical	13	16
Multi Specializations	32	38
Age		
≤10 years old	12	14
11-20 years old	22	26
>20 years old	50	60
Overseas experience		
≤5 years	40	47
6-10 years	13	16
11-15 years	13	16
>15 years	18	21

Source: Questionnaire Survey

Table 2 below shows the markets that the studied Pakistani contractors have ventured. Although the markets operated by Pakistani contractors range from being contiguous to the distant, there appears to be gradual progress pattern in the way the surveyed Pakistani contractors developed overseas. The surveyed contractors have large presence in United Arab Emirates (UAE), Saudi Arabia and Qatar which are geographical and physically close countries in contrast to the Angola and Malaysia located at far locations. The interviewees described that these markets were advantageous and more appropriate for their firms as inferred by the fact that these markets had good economic growth and sound profit potential, and geographically these markets are near to Pakistan hence costing less expense for mobilization of equipment, labor and material to these markets.

Table 2: Foreign markets ventured by the surveyed firms

Country	Nos.	Percentage
United Arab Emirates	42	22%
Saudi Arabia	36	19%
Qatar	26	14%
Afghanistan	14	7%
Oman	12	6%
Angola	6	3%
Malaysia	4	2%

The statistical results in Table 3 show the criticalness of the barriers in the internationalization of Pakistani contractors. The surveyed contractors have ranked one external barrier important which is inaccessible market information (MIR=3.93 and Standard Deviation=0.867), and two internal barriers important which included start-up cost (MIR=3.74 and Standard Deviation=0.964) and foreign language (MIR=3.62 and Standard Deviation=0.854).

Table 3: External and internal barriers to internationalization

Variables	N	MIR	SD	Remarks
External				
Inaccessible market information	84	3.93	0.867	Important
Cultural differences	84	3.36	.906	Moderately Important
Foreign government restrictions	84	3.31	0.869	Moderately Important
Bureaucracy (long administrative procedures, laws and regulations)	84	3.12	0.942	Moderately Important
Intense competition in the market	84	2.07	0.947	Less Important
Internal				
Start-up cost	84	3.74	0.964	Important
Foreign language	84	3.62	0.854	Important
Limited financial resources	84	3.23	0.882	Moderately Important
Lack of management skills	84	2.64	0.630	Moderately Important

[3] stated that the market information regarding market size and market growth rate can have significant impact on the international market entry mode selection. According to [14], the target country where completion is judged too strong for export and equity entry modes, a company may select licensing or other contractual modes. If the market is growing at a fast rate, and this rate of growth does not seem sustainable over several years ahead, the firm will be suggested to strike into this opportunity without any delay and use non-equity entry mode preferably exporting or sub-contracting. The findings from our surveyed firms verify this statement as this barrier faced by surveyed contractors does influence the choice of company’s entry mode, as the firm sees the importance of market size and market growth rate for the continuity of work in international markets which is an important consideration for these firms. Hence, where the market information is not easily accessible, these contractors try to avoid those markets or enter through non-equity modes i.e. sub-contracting or exporting.

The company’s different international business risk acceptance depends on the financial condition, start-up cost and strategic alternatives of the company as well as the competitiveness of its competitive atmosphere and its experience. The perceived risk related to an individual market entry mode or country can influence a company’s choice of market entry mode in a significant way [3]. [15] stated that strategic goals for entering new international markets and the development of these strategies may influence the choice of international market entry mode. The findings from our firms revealed that the strategy is not to depend on one market however the companies have clear stated strategy regarding international market entry that they want diversification to ride out the dips in a particular market. According to the respondents obtaining an early stability in the new international market involves huge start-up cost and resource utilization, therefore, entering into sub-contracting or a joint venture is a more professional approach and later local subsidiaries can be created. These findings verify the theory of [15].

The foreign language has second highest mean and was considered second important internal barrier. Language is considered as the extreme mediator that enables linking and understanding. Language allows sharing the feelings, expressing the emotions and conveying complicated messages and knowledge. Foreign language proficiency allows access to the foreign markets (authorities, competitors and customers) and hence it helps to overcome the lack of market and local information. Though foreign language has been the critical barrier in the internationalization of our surveyed contractors, yet networks and social relationships circumvented this internal obstacle.

In general, while limited financial resources and lack of managerial skills had lower means, when combined, could detract from the interest to work in specific countries. However, these barriers were outwitted by adopting sub-contracting and joint venture entry modes in foreign countries.

Table 4: Preferred Market entry modes (Operational modes) adopted / Modes of market presence

Variables	N	Mean	S.D	Remarks
Sub-Contracting	84	4.33	.650	Often.
Joint Venture	84	3.95	.854	Often.
Exporting	84	3.57	1.063	Often.
Own Representative	84	3.43	.966	Sometimes.
Wholly Owned Subsidiary	84	3.24	.983	Sometimes.
Merger & Acquisition	84	2.38	.909	Rarely.

The scale of investment and control in overseas business centered changes in the entry modes choice of the Pakistani contractors (Table 4). While the main entry mode chosen by the Pakistani construction firms is a type of sub-contracting, exporting and equity joint venture, other mechanisms consists of own representative, establishment of completely owned subsidiaries and mergers & acquisitions. Mostly firms initiated their internationalization with temporary market presence by providing management services for the particular projects and exporting main employees on term basis, employees who returned to Pakistan at the end. For example, in Qatar a firm joined Brazilian construction firm to expand its local skill and expertise base, its main strategy for internationalization was to transfer skill knowledge and expertise by behaving as the subcontractor (piggybacking) in the start. Although in traditional exporting no physical movement is involved, this strategy of market entry is found to be the most effective method for serving global markets. Later the firm made equity joint venture with the local Qatari firm in the second year of its establishment. The firm later expanded its business sphere to Saudi Arabia also by forming joint venture with the same Qatar based construction firm.

One of the representative said that entering the foreign market through sub-contracting was due to the network of the company. To demonstrate the nature of this network or relationship, the respondent stated that "It all came up of a chance job we did. A major building was constructed by us for a Pakistani minister who had good terms with the government official in UAE. They were in dire need of a firm to do emergency works on the airport and the roads. We were asked to start this work at earliest. We did it successfully and our work was acknowledged."

The finding from our investigated firms revealed that they give an important consideration to the continuity of work in the foreign country and the markets they enter are mostly atomistic and constitutes of many competitors. Therefore they normally use the non-equity modes for initial penetration into the new market and with the time which is normally two or three years when they got enough knowledge of the market and got enough resources, capabilities and networks to compete with the large companies around, they establish the joint ventures or wholly owned subsidiaries. Parallel to this, few firms has yet another vision of the subject, which is to simply ignore the markets where competition is intense and unfavorable and to pay attention on the markets which are less competitive.

5. Conclusion

This study involved an empirical assessment of the internationalization of Pakistani contractors in the integrated context of key conceptualizations of internationalization. Overall, the study has brought up useful insights about the foreign market choice, barriers and market entry modes of Pakistani contractors by employing a triangulation approach. The findings showed that UAE, Saudia Arabia and Qatar were the main markets ventured by Pakistani contractors. Further, inaccessible market information, cultural differences and foreign government restrictions were key external barriers whereas start-up cost and communication issues were key internal barriers for international market entry of Pakistani contractors. Among the foreign market entry modes, sub-contracting and joint ventures are the important and mostly used modes of entry.

In spite of the significant findings, the study has limitations related to sample size. The conclusion of this study should be interpreted in view of the limitation of the data and that the research has been conducted on contractors from Pakistan only. Future studies may be carried out by including more samples and other research methodologies such as qualitative approaches. This study could be further extended to include alternative forms of data collection, with research conducted longitudinally.

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A Network-Theory Based Model for Stakeholder Analysis in Major Construction Projects

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Abstract

The high complexity and uncertainty of major construction projects (MCPs) call for a rigorous approach to manage the relationships and conflicting needs of stakeholders who act a pivotal role in project success. During the past decades, there has been an unsatisfactory stakeholder management record in the construction industry. Despite a rapid advancement of stakeholder analysis methods, project teams still face challenges in completely identifying stakeholders and their concerns, and accurately evaluating their relationships and impacts. These obstacles are attributed to the weaknesses of the current stakeholder analysis practice, in which project teams categorize and prioritize stakeholders by assessing their individual attributes based on empirical knowledge of team members. The weaknesses are threefold. First, 'hidden' stakeholders are often missed out in the identification process due to cognitive limitation. Second, the accuracy of assessment is limited due to subjectivity. Third, the basis for evaluation relies heavily on the dyadic relationships between project teams and stakeholders; neglecting both the actual stakeholder interrelationships and stakeholder issue interdependencies.

In reality, a project environment can be perceived as network systems composed of interconnected stakeholders, as well as of interrelated stakeholder issues. The characteristics of and propagating effects produced by these network structures determine the perceptions, salience and impacts of project stakeholders. To overcome the limitations of current practice, this paper proposes an innovative stakeholder analysis approach based on the network theory. In this paper, the sources of stakeholder complexities in MCPs are firstly discussed. The existing stakeholder analysis methods are reviewed with their limitations highlighted. A network-theory based stakeholder analysis approach for MCPs is proposed. Its process and network analysis techniques are introduced. Taking a network perspective to analyze both stakeholders and their interests can benefit researchers and industry practitioners by improving the accuracy, completeness and effectiveness of the stakeholder management practice in construction.

Keywords: stakeholder analysis; network analysis; network theory; major construction project

1. Introduction

Managing stakeholder relationships and interests has been increasingly regarded as a critical yet challenging task in the successful delivery of major construction projects (MCPs). MCPs involve numerous stakeholder groups who have discrepant concerns and expectations, and are interrelated by multiple kinds of social interactions in the project. MCP development can readily produce positive and negative impacts to the vested interests of stakeholders; who are making their best endeavor, in different ways, to increase the project team's salience in avoiding their interests from being put in peril [7]. Stakeholders can even be allied to build a stronger resistive force in safeguarding their interests. Ineffectively addressing stakeholder needs often harms the project and leads to failures.

Stakeholder analysis is an essential element of MCP management to understand the stakeholder environment; conventionally, it comprises four main parts: (1) identification of stakeholders and issues; (2) stakeholder classification based on individual attributes; (3) examination of stakeholder relationships, and (4) evaluation of stakeholder influences [9]. Notwithstanding the recent growth of project stakeholder analysis theories and practical

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approaches, the record of stakeholder management in MCPs has still been criticized as unsatisfactory. There are limitations in the existing stakeholder analysis practice, which have put obstacles on project teams to fully identifying stakeholders and their issues, and accurately evaluating their relationships and impacts [11]. This paper aims to improve stakeholder analysis practice in MCPs by proposing a network-theory based model. The paper firstly reviews the existing stakeholder analysis methods and highlights their weaknesses, a network perspective is then suggested to tackle the problems. Lastly, a network-theory based model for stakeholder analysis in MCPs is proposed, with its process and network measures discussed.

2. Stakeholder complexities in MCPs

Stakeholders refer to any groups or individuals “who can influence the project process and/or final results, whose living environments are positively or negatively affected by the project, and who receive associated direct and indirect benefits and/or loss” [5]. In MCPs, the complexity of stakeholders can be analyzed from three aspects: (1) stakeholder issues and their interdependencies, referring to what stakeholders concern about in the project and how these stakes are interrelated; (2) relationships and interactions of stakeholders, referring to the social interactions of these entities; and (3) dynamics of stakeholders and issues, referring to how the stakeholder community and stakeholders’ interests change over time as the project proceeds. This section discusses stakeholder complexities in MCPs in detail.

2.1. *Stakeholder issues and their interdependencies*

The development of MCPs can readily attract and influence the vested interests of various stakeholder groups. Stakeholder issues, being described as the vested interests or concerns of project stakeholders, are often discrepant and dynamic owing to the disparate stakeholder backgrounds in the changing project circumstances. New stakeholders and issues often emerge in response to the changing environment; priorities of issues may also vary among different stakeholder groups. The conflicting stakeholder interests may result in project threats and failures if they are insufficiently accommodated. Comprehensive identification and prioritization of stakeholder interests have attracted attentions in previous studies. Li et al. [5] identified the main stakeholder concerns in the planning and design of large public infrastructure projects and investigated their different priorities among the government, general public, pressure groups and the affected vicinity. Zeng et al. [13] identified the key stakeholder issues in major engineering projects which relate to the fulfillment of project social responsibility. Existing publications have enriched our understanding about stakeholder concerns in MCPs. However, the evaluation and prioritization of issue importance have relied heavily upon the subjective judgment of individual stakeholders; disregarding the actual interdependencies between stakeholder issues and the propagating impacts produced by the issue network. As such, a rigorous method is in need to analyze stakeholder issue interdependencies and assess their impacts on each other.

2.2. *Relationships and interactions of stakeholders*

In MCPs, stakeholders are connected directly or indirectly by many kinds of relationships across functional and organizational borders, so they are embedded in various social networks instead of being isolated in vacuum. Earlier studies paid much attentions on formal relationships of stakeholders; for instance the contractual relationships between project organizations concerning resources sharing and supply of construction services [8], and the hierarchical relationships between intra-organizational project participants. Recent studies shift the focus towards informal relationships of stakeholders, and pay considerable efforts on improving the strategies of relationship management towards project success. In the studies of Cross and Parker [3], informal stakeholder relationships are classified into four kinds; including collaborative relationships, information/knowledge exchange relationships, power/influence relationships, and interpersonal relationships (e.g. emotional support, trust). Chinowsky et al. [2] also stated that communication and information/knowledge sharing are important social networks to be analyzed for achieving high performance in MCPs. Stakeholders do not exist independently in a project environment. The relationships and interactions of stakeholders are major factors determining stakeholders’ behaviors and strategies to safeguard their vested interests. Accordingly, a systematic method is needed to examine the interactions of stakeholders and their roles in these relational structures.

2.3. *Dynamics of stakeholders and issues*

The composition of stakeholder community is changing over time in response to the dynamic project environment, so as stakeholder relationships, their issues and issue interdependencies. To cope with such dynamics, continuous monitoring and updating are necessary for the entire stakeholder analysis process regardless of the methods adopted.

3. Existing project stakeholder analysis methods and their limitations

Due to the highly uncertain, volatile and complex nature of MCPs, the stakeholder environment in MCPs is also highly complicated, requiring a set of systematic methods and procedures to manage stakeholder relationships and issues. Stakeholder analysis is essential in stakeholder management process as it allows project teams to understand the stakeholder environment and develop appropriate engagement strategies. This section reviewed some traditional stakeholder analysis methods in previous studies and highlighted their limitations.

3.1. *Attribute-based stakeholder classification*

Stakeholder Salience Model is an attribute-based classification method widely used in the construction management domain [6]. Power, legitimacy and urgency are three key attributes forming the basis of classification. Power is described as the capability of stakeholders through relationship dependency and resources occupation [12]. Legitimacy describes how appropriate the stakeholder claims or behaviors are according to the norms and core values of social organizations. Urgency refers to the level in which a stakeholder claim requires instant response or awareness, depending on the time sensitivity of the issue and its necessity to the stakeholder [12]. By considering stakeholders' possession of these attributes, project management teams can perform stakeholder categorization, determine the degree of salience paid on stakeholders, and assess their impacts. This method is time-efficient as data can be easily obtained via focus groups or interviews. However, the attribute assessment and classification of stakeholders are perception-driven and may result in bias; for example, the same stakeholder may be put into different classes by different respondents.

3.2. *Impact-probability matrices*

In impact-probability matrices, project teams assess stakeholder influences and predict their likely behaviors by categorizing stakeholders in terms of two aspects [7]: (1) the level that a stakeholder can impact the project; and (2) the probability for this impact to occur. There are many variations of this method in the project stakeholder management domain, e.g. stakeholder vested-interest impact index, power/interest or power/predictability matrices.

3.3. *The Stakeholder Circle tool*

Stakeholder Circle methodology covers the stakeholder management process more completely by including ways for stakeholder visualization, engagement, and evaluation of communication effectiveness [1]. Comparing with the above methods, this tool prioritizes stakeholders and assesses their impacts in a more structured way. For instance, Bourne [1] modified the stakeholder salience model and replaced legitimacy with another key attribute, proximity; which describes the extent that a stakeholder is directly engaged in the project. This method also illustrates the nature of stakeholder influences by indicating the directions of stakeholder impacts to the project team, as well as the scope and degree of impacts. In certain extent, this tool considers the dyadic relationships between stakeholders and focal organization in its assessment. However, in reality, stakeholders are connected by many social interactions and embedded in relationship networks. This tool, building upon dyadic stakeholder relationships, are thus inadequate to address stakeholder complexities in MCPs.

This section reviews some important existing stakeholder analysis approaches developed in previous studies. It indicates that the current stakeholder analysis methods in MCPs are linear and subjective. They have disregarded some important aspects of stakeholder complexities, such as *stakeholder interactions*, *stakeholder issue interdependencies*, and *propagating impacts produced by these network systems* (i.e. stakeholder network and issue network); resulting in limited accuracy and effectiveness in project stakeholder analysis. The next section discusses the potential of applying a network perspective for addressing stakeholder complexities in complex project environment.

4. Potential of using a network perspective for stakeholder analysis in MCPs

4.1. *Network-theory based analysis*

The network theory was firstly introduced in 1930s, this methodology systematically analyzes the relational structures of a definite set of actors, by visualizing the structures using sociographs and quantitatively deciphering the structural pattern with network indices [4]. According to Wasserman and Faust [10], the performance and robustness of a network system are readily affected by the interconnected elements within this system, as well as the ways that these elements are linked together. As such, using network-theory based approach for stakeholder analysis can help to understand interactions of stakeholders, cause-and-effect relationships between stakeholder issues, as well as the resultant impacts of these on project delivery. There are five general steps of the network methodology, namely (1) defining the network boundary (i.e. which stakeholders/issues to be included); (2) identifying and assessing the interdependencies of network actors ; (3) visualizing the networks; (4) examining the network structures using network indices; and (5) developing management actions and strategies in response to the analysis results [12].

4.2. *Why using a network perspective*

To improve the conventional stakeholder analysis practice, a network perspective can be used to analyze two key aspects of stakeholder complexities, namely (1) *stakeholder interactions* and (2) *stakeholder issue interdependencies*. In MCPs, stakeholders are connected by many different kinds of social interactions, e.g. trust and communication [8]. In this study, we focus on knowledge exchange between stakeholders among the various kinds, as it is an essential type of social interactions for collaboration of project participants. Herein, knowledge exchange refers to the transfer of skills/expertise to explain the ways of doing something and to explore ways for improvement [2]. Stakeholder issue interdependencies in the project is another key aspect to be analyzed because issues emerging from a MCP are interrelated. The presence and incidence of an issue can trigger the other issues to occur and affect their perceived importance under chain effects. The issues of a project are under direct, indirect or mutual impacts from each other. Neglecting these interdependencies will reduce the accuracy and completeness of stakeholder impact assessment. The following section introduces a network-theory based approach for analyze stakeholder interactions and stakeholder issue interdependencies in MCPs.

5. The network-theory based model for stakeholder analysis in MCPs

Figure 1 shows the proposed network-theory based stakeholder analysis model for application in MCPs. This model aims to analyze stakeholder relationships and interests from a network perspective, identify key stakeholders and issues, and develop appropriate management strategies to engage stakeholders and accommodate their concerns.

This model comprise four major steps and two parts of network analysis: (1) *establish the context and stakeholder analysis planning* – this is to create an initial understanding of the project environment (e.g. project goals, objectives, constraints, organizational structures, etc.) and the context in which project stakeholder analysis will be undertaken; (2a) *a network-theory based analysis of stakeholder-related issues* – this analysis helps to identify critical issues and issue-interdependencies which exert great direct/propagating impacts on other issues/links; (2b) *a social network analysis of stakeholders* – in this model, the knowledge exchange relationships between stakeholders are analyzed based on three relationship attributes (frequency, quality of knowledge, and timeliness of access). In other occasions, social interactions of various kinds (e.g. information flow, communication) can be studied. This analysis helps to identify key stakeholders (e.g. central connectors, boundary spanners, knowledge brokers) and also peripheral ones. It should be noted that Step (2a) and (2b) should be conducted in parallel, as their results complement each other. The network measures used in analyzing stakeholder knowledge network and issue network are introduced in Table 1; (3) *consolidate the network analysis results* – the outcomes of this step are the lists of key stakeholders (with their roles/positons in project knowledge exchange), and the critical issues and interdependencies which worth project team's attention; and (4) *develop and simulate stakeholder management strategies* – this is to formulate proper management measures for improving stakeholder engagement (e.g. decentralizing the network for long term knowledge sharing, protecting the weak ties, exploring innovative knowledge from peripheral stakeholders) and accommodating critical stakeholder issues. Quick simulation of the proposed measures can be carried out by re-calculating the network measures. Since the stakeholder community, their social interactions and issues are changing in response to project environment, the whole process of the model require continuous recording, monitoring and updating; as well as continuous communication and consultations with the stakeholders involved.

Table 1: Network measures and their explanation in the network-theory based stakeholder analysis model.

Network measures	Theoretical meaning	Practical meaning for: Stakeholder knowledge network	Practical meaning for: Stakeholder issue network
Network density	The ratio of current links to the greatest number of ties if all nodes are interlinked	Denser network → more occurrence of knowledge exchange	Denser network → more issues are interconnected
Network cohesion	The average distance of path to meet nodes of a network	Higher cohesion → longer knowledge flow time	Higher cohesion → more complex network
Degree centrality	The number of immediate links directed to (in-degree) or given off by (out-degree) a node	Higher degree → more knowledge flow to/from a stakeholder	Higher degree → larger immediate impact to/from an issue
Betweenness centrality	How often a node falls between two non-adjacent nodes based on shortest path	Higher betweenness → greater control by a stakeholder on its two neighbours	Higher betweenness → greater control by an issue on its two neighbours
Closeness centrality	How far is a node to meet every other else in the network	Higher closeness → harder for stakeholder to act alone	Pay more attention to issues with higher closeness
Brokerage	The role of a node (e.g. representative, gatekeeper) when bridging subgroups	Higher brokerage → easier to discover new knowledge in other subgroups	Pay more attention to issues with higher brokerage

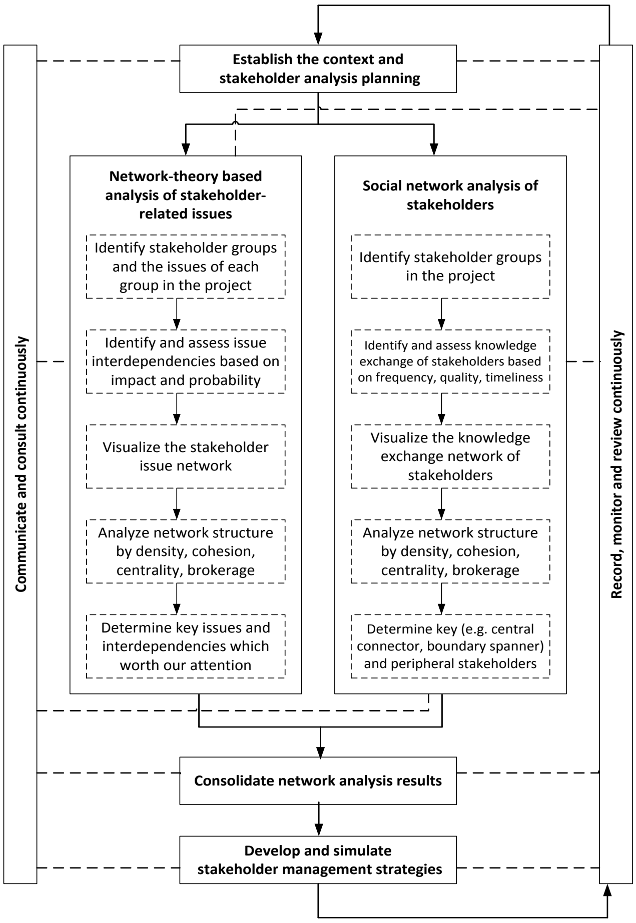

Figure 1: The conceptual network-theory based model for stakeholder analysis in MCPs.

6. A hypothetical case study

This section presents a hypothetical case study to illustrate the use of the proposed network-theory based approach. Due to the limitation of space, only part of the network analysis results are shown.

6.1. *Drawing the network boundary*

In this case study, two networks are built and analyzed: (1) stakeholder knowledge exchange network, and (2) stakeholder issue network. Drawing network boundaries is the first task to be done, which involves the identification of stakeholders, knowledge exchange relationships of stakeholders, stakeholder issues, and issue interdependencies. Snowball rolling method is a suitable means for stakeholder identification because it helps to recognize nearly all stakeholder entities; while desktop studies on project documents, interviews and workshops with core project team members can be conducted to identify stakeholder issues in the project. Questionnaire surveys, in matrix form, can be used to define and assess stakeholder knowledge exchange interactions (based on the frequency) and issue interdependencies (based on the impact exerted by an issue on others and the probability of such impact). Table 2 shows the stakeholder groups and the issues of each group in this hypothetical case. In this case, the six stakeholders are linked by 28 knowledge exchange relationships, resulting in a stakeholder network N(6,28). Besides, the issues of stakeholders are related by 72 interdependencies, resulting in an issue network N'(19,72).

Table 2: Stakeholders and their issues identified in the case project.

Stakeholder	Stakeholder code	Issues of each stakeholder	Issue code	Issue category
Client	S1	Delivering the project within budget	S1C1	Cost
		Time overrun	S1C2	Time
		Performance of contractors	S1C3	Quality
		Company image and reputation	S1C4	Ethical
Executive project manager	S2	Sequencing of construction activities	S2C1	Time
		Communication and collaboration of the project team	S2C2	Project management
		Pollution and environmental mitigation	S2C3	Environmental
Lead design consultant	S3	Building aesthetics	S3C1	Quality
		Meeting the requirements of client and end users	S3C2	Quality
		Green design	S3C3	Technical
Contractor	S4	Construction safety	S4C1	Safety
		Contractual dispute and claims	S4C2	Contractual
		Inflation of material and labour cost	S4C3	Cost
		Site logistics	S4C4	Technical
		Technical complexity	S4C5	Technical
Quantity surveyor	S5	Project cost control	S5C1	Cost
		Contract administration	S5C2	Contractual
Subcontractor team	S6	Construction safety	S6C1	Safety
		Material and labour supply	S6C2	Technical

6.2. *Visualizing the networks*

This case study applies NetMiner for network visualization as it is capable in exploratory network data processing. Basically, the main node sets and link matrices are the primary inputs for this software. The stakeholder knowledge exchange network and the issue network are shown in Figure 2(a) and 2(b) accordingly. In both figures, node shapes represent the stakeholders; while a more central stakeholder is denoted by a bigger node. In Figure 2(b), node colors indicate the issue categories.

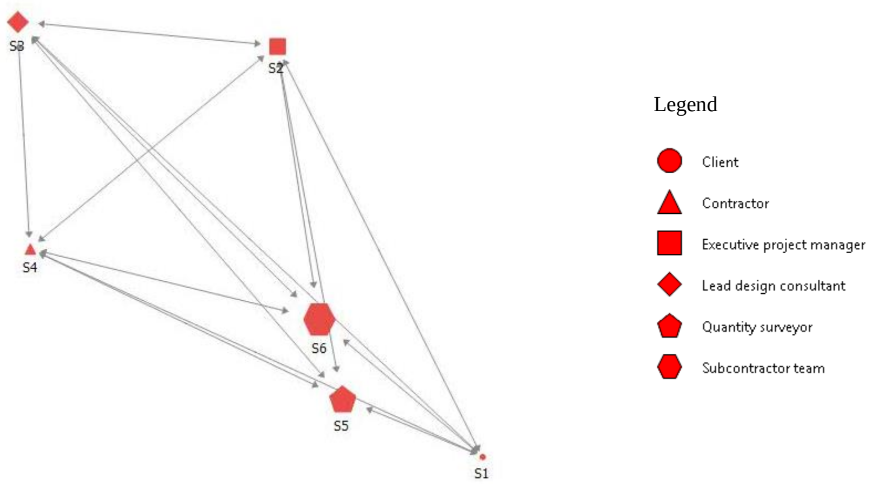

Figure 2(a): Stakeholder knowledge exchange network in the case project.

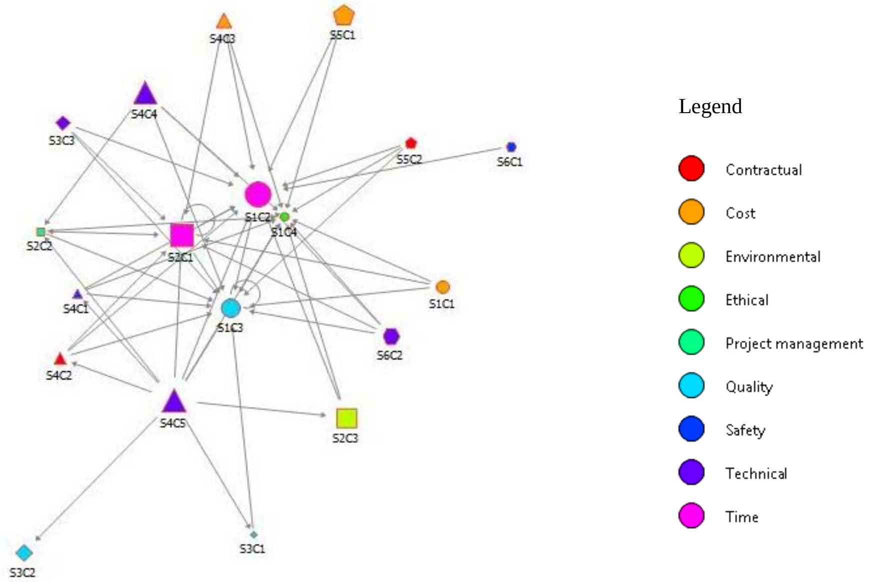

Figure 2(b): Stakeholder issue network in the case project.

6.3. *Preliminary network analysis results*

Degree centrality refers to the number of immediate links directed to (in-degree) or given off by (out-degree) a node. Figure 3(a) and 3(b) shows the out-degree centrality maps of stakeholders and stakeholder issues in the case. According to Figure 3(a), S1 (client), S2 (executive project manager), S3 (lead design consultant) and S4 (contractor) occupy the central position of the concentric map. All these four stakeholders have the maximum out-degree value of 1, indicating that they transfer knowledge to each of the other stakeholders very frequently. According to Figure 3(b), three concerns of the client, namely S1C2 ('Time overrun'), S1C3 ('Performance of contractors'), and S1C4 ('Company image and reputation') are the most central issues in the concentric map. They are ranked top three in the out-degree result, with the values of 0.56, 0.22 and 0.22 respectively; indicating that they are the issues giving the greatest direct impact to other immediate neighbours in the case.

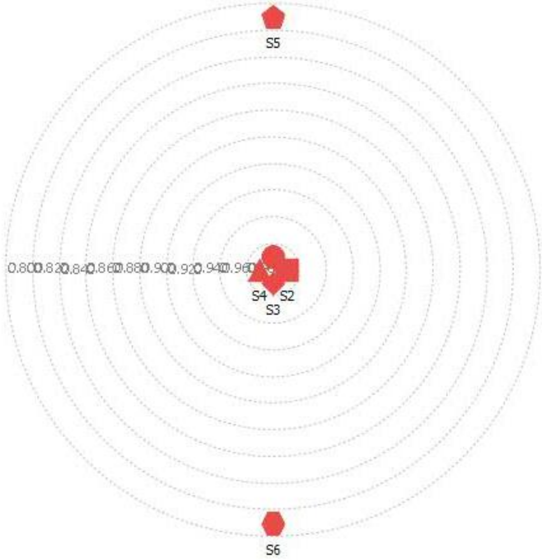

Figure 3(a): The concentric out-degree centrality map of stakeholders

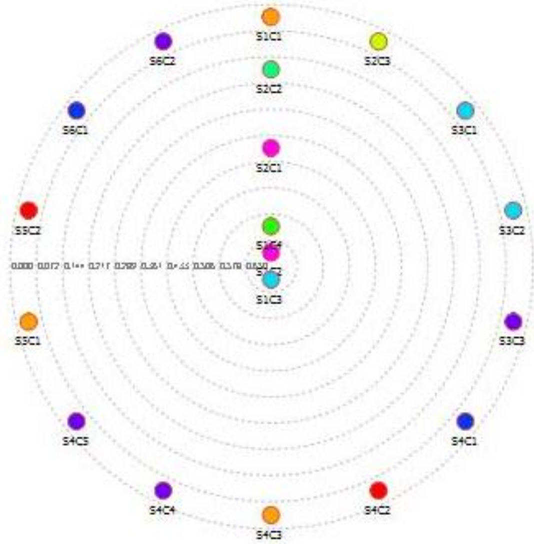

Figure 3(b): The concentric out-degree centrality map of stakeholder issues

7. Conclusions

The existing stakeholder analysis practice in MCPs has been criticized as linear and intuitive. These methods often omit the 'hidden' stakeholders and issues, overlook stakeholder interrelationships and issue interdependencies, thereby become insufficient to address stakeholder complexities in MCPs. This paper suggests a network perspective to tackle these problems, and proposes a conceptual network-theory based model for stakeholder analysis in MCPs. By using network analysis, the model helps to: (1) recognize as complete as possible the project stakeholders and their concerns, (2) assess social interactions (e.g. knowledge exchange) of stakeholders and the cause-and-effect relationships of issues, (3) mathematically analyze these network structures, (4) identify the key stakeholders and issues based on their network roles and positions, and (5) develop corresponding actions to engage stakeholders and accommodate their needs. In future, empirical case studies of MCPs in different types and contexts can be carried out to put the conceptual model into real application. The model can help to increase the overall accuracy and effectiveness of stakeholder analysis in construction, and its application can provide practical insights concerning stakeholder relational structures and issues in MCPs.

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Mentoring on Retention of Employees in the Construction Sector: A Literature Review

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Abstract

The business world has long known and relied upon mentoring a proven technique for developing talent, mentoring is experiencing resurgence because business leaders not only recognize the benefits of transferring knowledge among employees. Organizations today face a challenge regarding the mentoring and retention of key knowledge employees. Few articles on mentoring, retention have appeared in the human resource development (HRD) literature. Changing workforce demographics, more competitive recruiting and faster turnover among young employees are creating unprecedented knowledge retention problems in many industries, threating to reduce the capacity for innovation, growth and operational efficiency. The article aim to look at the experiences and problems contributing to retention of employees, examines practice on mentoring through the lens of HRD within construction companies. Describes better practices organizations can use to address the threat of lost knowledge caused by changing workforce demographics. Study adopted a literature review method of data collection, with a special focus on mentoring. The data in the report was mainly qualitative, based on content analysis, and historical data. The study indicated knowledge transfer assists employees in improving their skill sets which increases their marketability and potential for them to pursue career opportunities. The study provide useful lessons for the construction industry and stakeholders that knowledge retention and mentoring of employees are critical for sustaining future organizational performance, mentoring relationships assist organizations in promoting effective knowledge transfer and commitment that assist in the retention of key knowledge workers. The authors conclude with an agenda that identifies where researchers need to go with mentoring research and HRD to better inform the practice of mentoring in organizations and understand how mentoring relationships benefit organizations.

Keywords: Mentoring, employees, retention, skill, development.

1. Introduction

Employee retention is becoming a major issue with most employers. Many organizations have not kept up with the changing needs of the workforce causing many good people to leave. Combined with the growing worker shortage, they are unable to fill jobs with qualified people. Employee retention is most critical issue facing corporate leaders as a result of the shortage of skilled labor, economic growth and employee turnover. Many construction employees regardless whether they are skilled or unskilled workers, they move from one company to the next, especially now whereby no employee will stay with an employer for the rest of his or her life, people are being exposed to opportunities that they have never knew that they existed for them in various companies, due to this there is national and global impact for shortfall in talent and retaining employees within their various respective companies, The role of mentoring in fostering the development of employees is discussed as a component of a number of employee development theories.. It is not surprising that mentoring has been recommended as an essential tool for human resource development. Noteworthy advances have been made in understanding the nature, process, and outcomes of mentoring relationships. However, the literature on mentoring is still fairly young [1, 2] many questions about mentoring remain poorly answered or have yet to be thoroughly investigated, within the construction industry.

Mentoring is considered to be the oldest form of knowledge transfer [3]. For centuries, in agrarian and hunting societies, one was surrounded by many adults who served as occupational role models, i.e., mentors, and the knowledge that was passed down from these mentors benefited both the individual and the collective organization of which one was a part [4]. The transfer of knowledge and the retention of key knowledge workers, thus, is critical to organizational competitiveness [5, 6, and 7]. If such organizations do not have processes to promote effective knowledge transfer, productivity will suffer and organizational survival may be threatened. Conversely, if organizations do invest in knowledge transfer they risk increasing the marketability and job mobility of their employees which could potentially harm retention [8].

2. Purpose of the study

The purpose of this study is to contribute to a broader understanding of mentoring, mentoring relationships and their impact on individual and organizational outcomes. A significant percentage of the workforce, within the construction sector is nearing retirement age over the next ten years. These employees have acquired a tremendous amount of knowledge about how things work, how to get things done and who to go to when problems arise. Losing their expertise and experience could significantly reduce efficiency, resulting in costly mistakes, unexpected quality problems, or significant disruptions in services and/or performance. Mentoring is an interesting addition to the HRD (Human Resource Development) literature because many of the characteristics of an organization's, traditional approaches to employee human resources can't be easily changed. For example, turnover, retention of employees and the selection of processes may be able to slowly change the employee landscape, but they can't change a crucial element of human resources within organizations, the individual employees' characteristics.

2.1. *Objectives of study*

- To describe better practices that organizations can use to address the threat of lost knowledge.
- To determine the role of mentoring in HRD.
- To evaluate the impact of mentoring on retention of employees within organizations.

3. Literature Review

Mentoring relationships in the workplace may assist organizations in addressing this dilemma. Research in this area suggests that providing skill-building opportunities to protégés is positively related to personal learning in the workplace [9]. Yet, an unintended consequence of knowledge transfer via mentoring is the potential for increased job mobility for protégés and the resulting negative effect on organizational retention efforts [10]. Recent findings from a longitudinal study suggest that mentoring fosters organizational retention in part because the emotional bond established between a mentor and a protégé may contribute to higher levels of organizational commitment [11]. Mentoring relationships may operate, thus, through a dual pathway to impact organizational retention by assisting in the transfer of organizational knowledge while simultaneously developing the high-quality interpersonal relationships that strengthen a protégé's commitment to an organization. Mentoring as a form of strategic human resource management is an interesting addition to the HRD literature because it provides a mechanism of change for individual employees, within construction organizations. Having a powerful human resource development (HRD) organization is a worthwhile asset of companies, and an enterprise's efficiency is closely connected to human capital's managerial and developmental systems [12].

The relationship an employee has with his/her peers, colleagues and company has a significant impact on knowledge retention and transfer. The effect of mentoring relationship through knowledge transfer is that knowledge retention and transfer is an area that holds great potential for companies in terms of reducing the costs associated with turnover, and perhaps more important, in sustaining business performance. Companies are recognizing it as a priority. According to Aberdeen Group, 61% of human resources executives and line of business managers surveyed rated 'capturing and transferring knowledge from those who have it to those who need it' as a top workforce-related challenge [13]. A study by the Institute for Corporate Productivity found that a third of responding companies retain knowledge poorly or not at all when workers leave, while half think they're doing only "okay" at protecting organizational knowledge. Just two in ten think they are doing well or very well in knowledge retention [14]. Manpower's recent survey adds weight to these findings, 31% of employers indicated their organization does not have a proactive process in place to capture employees' job knowledge [15].

4. The role of mentoring in HRD

Mentoring is a process in which one person (mentor) is responsible for overseeing the career and development of another person [mentee] outside the normal manager/subordinate relationship in an organization. A mentor is someone who is concerned with a person's life's work in a workplace and helps her/him become what that she/he aspires to be through career, education and psychological support. [16] says that mentoring is an endeavor to transmit proficiency and expertise from practiced members in an organization to the less experienced. It is mostly used as a "fast-track" support scheme where in the senior members of the organization oversee the activity and performance of the more junior colleagues who have been identified as 'crown princes' kings of tomorrow. [17] take a more comprehensive view of the concept of mentoring and say that the mentors are supposed to contribute to the protégé on two dimensions; career building and psychosocial richness. Career building functions include promoting job related skills and behaviours of the mentees, patronizing their growth and advancement, and enhancing their outlook as a way to help them grow intrinsically as well as extrinsically along the hierarchy of the organization. Psychosocial richness functions include building behaviors, such as offering acceptance and providing friendship, that enhance the protégé's personal growth, identity and self-worth.

4.1. *HRD in the construction organization*

The construction industry has been considered to be one of the most dynamic and complex industrial environments [18]. It is a project based industry within which individual projects are usually custom built to client specifications [19]. The dynamic environment and changing demands of construction activities required the formation of the teams each time a new project is commenced with a new client. Most importantly, however, the external sources of workforces are very common in the industry [19]. Whilst the increasing use of external sources of labour has allowed the managing contractors to pass on risk and achieve greater flexibility, it has also made employee development and project coordination more complex, with a requirement for more highly skilled and experienced management [19]. Despite these challenging characteristics of the industry, literature on HRD within large construction organizations is scarce and much of the evidence relies on data gathered over last decades [18].

5. The Importance of Worker Retention and Knowledge Transfer

When a business loses employees, it loses skills, experience and “corporate memory”. The magnitude and nature of these losses is a critical management issue, affecting productivity, profitability, and product and service quality. For employees, high turnover can negatively affect employment relationships, morale and workplace safety. The cost of replacing workers can be high, the problems associated with finding and training new employees can be considerable, and the specific workplace-acquired skills and knowledge people walk away with can take years to replace. The problem of turnover can be addressed through a variety of pro-active retention strategies: workplace policies and practices which increase employee commitment and loyalty. Knowledge transfer initiatives on the other hand, ensure that the knowledge and expertise of a company’s employees its 'corporate memory, are systematically and effectively shared among employees. Employee retention and knowledge transfer are two elements of a more general concern that might be best termed ‘skills management, ’i.e., everything that has to do with recruiting, maintaining and developing the necessary mix and levels of skill required to achieve organizational and business objectives [19].

5.1. *Retention*

As an outcome of mentoring relationships in workplace settings, retention is of interest in this study because of its importance to organizational performance. For decades, management researchers have emphasized the importance of retaining talented employees through research on turnover. If organizations invest in talented employees through increases in their knowledge, the knowledge transferred to these employees is lost if they leave the organization, and the investment made to them. While recognizing that there will always be some voluntary turnover in an organization, retention rates should be somewhat high so that experienced workers are available to share their organizational knowledge with newcomers in the organization and to use their expertise to directly benefit their organization. Thus, in the knowledge economy, it is important to look at issues of retention; Traditional research has focused on the influence of job satisfaction on voluntary turnover [20].

Mentoring is a type of workplace relationship that may assist in promoting the retention of knowledge and talented knowledge workers. Protégés who reported receiving mentoring were more likely to indicate that they did not have plans to leave their organization to go and work in another organization. Knowledge workers are increasingly more important for organizational competitiveness today, so the knowledge transfer between employees and the retention of key employees is critically important. Organizations that have not been concerned with retention in the past, however, are now struggling to keep their skilled employees. In professions heavily dependent upon knowledge transfer such as medicine, engineering, and chemicals manufacturing, the pool of skilled workers is shrinking; thus, there is increased competition for the available workers [6]. Organizations with higher levels of mentoring had lower turnover; moreover, they suggested that the mentoring specifically assisted in developing protégés' knowledge and skills. Based on the above research, one may posit that the knowledge and feedback provided to a protégé by a mentor may influence the protégé's turnover intentions.

6. Best practices in retention and knowledge transfer

In order to address the threat of lost knowledge caused by changing workforce demographics. The heart of any knowledge-retention strategy is its knowledge, sharing practices. There are many sorts of methods that contribute to knowledge capture, sharing and re-application, after-action reviews, communities of practice, face-to-face meetings, mentoring programs, expert referral services, training, video conferencing, interviews, written reports, etc. While many of these practices are helpful for creating a general knowledge, sharing environment, the question remains which ones are most useful for addressing knowledge-retention problems? Based on the review of the literature, the list of retention practices that captures the main types of interventions discussed in the HR literature. They are as follows [19]:

- **Competitive and Fair Compensation** is a fundamental starting point in most strategies to attract and retain employees. However, there is general agreement that compensation levels do not single-handedly guarantee employee retention. Common benchmark and position wage and salary structures to be fair and competitive.
- **Adequate and Flexible Benefits** can demonstrate to employees that a company is supportive and fair, and there is evidence to suggest that benefits are at the top of the list of reasons why employees choose to stay with their employer or to join the company in the first place. Many companies are responding to the increasingly diverse needs of their employees by introducing a greater element of choice in the range of benefits from which their workers can choose. Flexibility in benefits packages can enhance retention, as it creates responsiveness to the specific needs and circumstances of individual employees.
- **Training, Professional Development, and Career Planning are** effective ways to enhance employee retention. Training constitutes a visible investment that the company makes in the worker, providing him or her with new skills, and greater competencies and confidence. Training often leads to work that is more intrinsically rewarding. Combined with effective communication about how an employee's efforts at developing skills will lead him or her to more challenging and meaningful positions within the company, training encourages workers to make longer term commitments to their workplace: it permits them to see a future with the company. All of the companies we interviewed were very active in the area of skills training and professional development. Many have put in place effective internal promotion programs that allow even their unskilled and semi- skilled workforce to move towards positions of greater responsibility and remuneration within the company.
- **Knowledge Transfer – cross-training, coaching and mentoring, phased in retirement.**
  While employee retention practices seek to retain workers, knowledge transfer practices seek to retain skills, through both formal and informal exercises in information sharing and the building of collective knowledge. Mentoring and coaching, phased in retirements, and cross-training and job rotation, are types of knowledge transfer that overlap with training

7. The impact of mentoring on retention of employees within organizations

Though viewed as a key aspect of mentoring [3], knowledge transfer has been primarily examined at the interfirm level [21], at the interdepartmental level [22], and at the team level [23]. [24] suggest that much research on knowledge transfer has a more macro focus, examining the transfer of knowledge between and within organizations. Knowledge management articles highlight knowledge transfer as a key mechanism for organizational success, yet a gap exists between practice [25] and formal research [26, 24].

7.1. *Mentoring saves money, retains workers, builds leadership, and growth talent*

Mentoring contributes to employee growth and tenure. In the long run, a well-organized and managed program can save the company thousands of rands.

- **Reduced turnover and recruiting costs.** Mentoring relationships can help retain talented people because they have a stronger commitment to the organization [27]. Talent remains much less likely to leave if they feel supported in their work and made aware, for example, of new opportunities that their mentor suggests.
- **Assistance in transferring knowledge from the retiring workforce to new workers.** Many mentoring relationships help younger employees learn from those who will retire soon. Pairing junior staff with more senior staff can reinvigorate the enthusiasm of senior employees as they transfer crucial knowledge to the next generation of workers. This reduces the loss of the tacit knowledge from seasoned veterans leaving the workforce.
- **Helping employees learn skills and gain knowledge.** Mentoring is an excellent example of informal learning, which is the way people learn 80% of the time in the business world [28]. A mentoring program reduces training costs due to the mentor/mentee informal learning relationship, which often deals with content one-on-one that otherwise would be covered in a formal course. It also brings new employees up to speed quickly in those first few months of employment.

8. Conclusions

Retaining good employees is critical to a firm's long term success. And in the engineering and construction markets, employee retention is especially serious since the job market is tight and competition is fierce for top candidates. Companies simply cannot afford to ignore employee retention. Retaining organizational knowledge in the face of changing workforce demographics is a complex challenge that requires simultaneously confronting the problems created by an aging workforce, a shrinking talent pool and increasingly restless employees. The most effective knowledge retention strategies will require a multifaceted approach and a long-term commitment on both the leadership of an organization and the employees. In this paper, the authors have reviewed current perspectives on mentoring and HRD. Because knowledge is a key resource today, a more systematic understanding of how knowledge is shared and transferred in organizations is needed in order for organizations to be able to better manage it. Organizations must understand the types of processes that facilitate effective knowledge transfer between individual employees, while simultaneously retaining knowledge in the organization so it can benefit the organization and employees.

Attention must also be given to understanding the mentoring behavior’s that foster a protégé’s affective commitment so as to mitigate the potentially negative effect of knowledge transfer on retention. The provision of mentoring functions to protégés in an organization may assist an organization in meeting two critical goals for ongoing effectiveness: knowledge sharing and retention. It seems that the issue of mentoring and human resource development in construction organizations can generally be considered as a good field of research and vast topics of research can be defined in this regard.

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A Framework for Affordable Housing Governance for the Nigerian Property Market

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Abstract

Nigeria is perhaps facing the worst housing deficits in its existence with a homeownership of less than 20% and a housing shortage greater than 30 million. The deficits would lead to a crisis and consequently lead to poor standards of living, unaffordable house prices, high mortgage payments, abandonment, outbreak of diseases, dilapidation, and high maintenance costs. The main research from which this study forms part aims to develop housing governance. This current study aims to identify and the categorize factors accounting for the hosing deficits. Based on a cross section survey questionnaire the findings lead to the conclusion that the problems in the housing industry can be explained by policies, regulations, legal issues, market, economic and the construction industry. The discussions and results have some significant implications to the governments. For now, the government has to play multiple roles of providing housing and that of a market enabler.

Keywords: Procurement, government, systems management, housing deficits, median income

1. Introduction

Housing is expensive to own and operate. For most households that own their homes, it is probably the single most expensive investments and for those that rent, it represents the single most significant monthly or annual expenditure. The relationship between adequate housing and national productivity is very strong and positive. A country with adequate housing also means that such country would spend less on the preventions and controls of diseases, has reduced in crime rate and enhancement in social integration. For the pensioners or retirees, housing is to them a security issue. Housing is a measure of quality of life. However, housing in most of the developing countries is inadequate. There are several indices to measure the affordability of housing in a country. But, two of these indices are mostly applicable. According to one of these, housing is affordable if a rental cost, or mortgage repayment does not exceed 30% of household income for households in the lowest 40% of the income distribution range [1]. For rental purposes, the 30% includes utility bills, including for electricity, water, gas, sewage and garbage collection. In cases of a mortgage, the amount includes the actual consideration, tax, insurance, utilities, and maintenance. This definition is referred to as the 30/40 rule. Affordable housing is also defined in terms of 'median multiplier' [2]. The Demographia compares the median house prices to the median household income to measure affordable housing based on annual international Housing Affordability Survey. However, based on either of these definitions, housing in all major cities in Nigeria is 'severely unaffordable'. For instance, cumulatively, annual expenditure for the rental in the cities is ₦77,762 or 30.7% of the household monthly income [3]. With utility bills, the figure goes up to more than 40% of household income. Due to lack of accuracy on the median income, the mean income is used as proxy here. The mean income is 41,000 for more than 90% of Nigerians or 11,000 for more than 75% of Nigerians [3]. To put this study in context, while literature contains sizeable evidence on apparent causes of housing shortage in Nigeria [i.e.3, 5, 6,], but due to methodological issues and

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‘compartmentalisation effect’, systemic explanations cannot be made on how to reduce the shortage. With this background in mind, this paper reports part of a study that aimed to develop housing governance for the Nigerian housing sector to facilitate affordable housing delivery. This current paper addresses itself to identification of the causes of housing shortages in Nigeria.

2. Background

At 2014, the population was 178 million and estimated to increase to 205millsion in 2020 and will near 300 million in 2050 [7]. The per capita is US$3 000 with 3.8% higher rate of urbanization [8]. In 2014, the GDP was ₦67, 977,459.22 of which, the real estate accounted for ₦5, 155,727.95 (or 8%). In the third quarter of 2015, the GDP posted ₦18, 208,475.09 and the real estate was valued at ₦1, 360,104.16 or 8.74 % [9]. At 2013, the real estate sector contributed 8.03% to the GDP. In 2014, the Nigeria property market was valued at US$41 billion [8]. As part of the Gross Capital Formation (GCF), housing constituted 18.99%, 24.48% and 28.07% in 2010, 2011, and 2012 respectively [10]. The housing industry constitutes about 42% of the total value of the real estate. Though the growth rate of the real estate of 9.18% in the third quarter is lower compared to the period in 2014 and with the rate in the second quarter of 2015, the performance of the real estate industry is considered low with the rate of urbanisation. However, housing deficits in Nigeria have remained a tropical issue, despite government interventions through policies, regulations and controls. Prices of houses have increased more than for any other products or services. The price to rent ratio also shows rent is increasingly significantly across the country. While housing prices has increased globally over the past decade, the case in Nigeria is remarkable. Based on World Bank’s estimate cost of building a house in South Africa is USD36,000, USD26,000 in India, but it is USD50,000 in Nigeria [10]. From 2001 to 2011, house price has increased by 284%, 209% and 161%, in India, Russia and South Africa respectively [11]. In Nigeria, over the same period, house price has increased by up to 500%. The increase in house prices has outpaced income by a significant margin, leaving mostly in medium and lower-income groups without access to affordable homes. While the monthly rental price for 4 executive house is USD 8,500 in Nigeria (Abuja), in other major Africa cities like Cairo (Egypt), Accra (Ghana) Cape Town (South Africa) and Algiers (Algeria) is USD 3,500; USD 5,000; USD 5,000 and USD 5,000 respectively [12](Knight Frank, 2015). Statistical analysis based on data on existing housing stock, population, home production rate, population growth rate from World Bank data, National Bureau of Statistics Nigeria and the National Population Commission Nigeria, revealed that the housing deficit in Nigeria is more than 30 million [13]. The annual supply of housing in Nigeria is approximately a unit per 1000 of the population. This is far less than the recommended 8-10 units per 1000 in developing countries. Therefore, it was estimated that, it would take close to 300 years for the housing deficits to close based on existing home production rate. However, in order to close the gap in the next 30 years, the home production rate will have to be 21 times its current rate.

The academic literature suggests that primarily, the reasons for the Nigerian housing deficit include: lack of access to finance, poor capital and budgetary allocation, poor monitoring of mortgage institutions, an inefficient land market, a disproportionate number of speculators, poor infrastructure (i.e. roads, electricity, water, and telecommunication), and tedious and often conflicting legal requirements. Additionally, the performance of the Nigerian construction sector has a negative impact on the provision of housing. The construction sector is characterised by cost and time overruns, poor workmanship, and high cost of materials. The prices of major construction materials and component have increased by up to 10 times over the last 16 years. Despite the improvements in the financial and capital markets, less than 1% of Nigerians have mortgage to finance their homes and while the mortgage rate could be up to 30% [8]. The ratio of mortgage to the GDP is one of the lowest in Africa at 0.58%, whereas in South Africa, Namibia, and Morocco is 22.04%, 18.21% and 13.85% respectively [8]. This leaves most Nigerians to self-finance their homes. In fact than more than 90% of existing houses were constructed through unstructured self-help [14].

Governments have introduced various measures and incentives to increase the housing supply. But the government has not been proactive in the formulations her of policies. For example, between 2007 and 2011, the expenditure on the housing segment remains very low at around 2% of the total capital expenditure [15]. In 2014, out of the ₦18.5 billion allocated to the Ministry of Lands, Housing and Urban Development, only N13.5 billion is allocated for capital expenditure on housing and urban development [8]. Assuming this amount was wholly committed to providing more homes, at ₦7 million per homes, only less than 3000 of two-bedroom bungalows could be provided in urban centres. This excludes the cost of land and other government charges and legal fees. However, the household income of more than 62% of Nigerians in the cities or 75% of the average national income is less than ₦20,000 [15] but the average rental value is ₦77,760 annually. The interpretation of this statistic is that more than 80% of Nigerians are unable to own a home. Under the National Housing Programme of 1993, homebuyers were expected to deposit 40% of the total building cost. Yet, as of 1995, only 18,500 units of the promised 121,000 units were constructed while house prices had increased by 350% from ₦70,000 to ₦350,000

[16]. The Housing Programme was constrained by the poor conceptualisation and ineffective processes in the acquisition of land. The Federal Housing Authority (FHA) established in 1973 to provide affordable housing to Nigerians, however, but it supplied less than 1000 units annually since inception. The problems faced by the FHA are similar to those facing the other programmes. However, while some of the reasons are known or obvious to most, some are not known or been addressed leading to governments and other stakeholders' inabilities to address the housing shortage from narrow and fragmented perspectives. It is this fragmentation in proffering 'solution' that accounts for the widening gap in the housing shortage and increase in house price. Existing studies are generally descriptive and primary data are collected from a stakeholder or professional in the housing industry. The numbers of factors included are often limited. This study begins to fill this void by expanding and perfecting the determinants of housing supply and involving more stakeholders and theories.

3. Outline of research design

The primary data were based on survey questionnaire. The survey was based on convenience sampling method and administered through hand delivery. Convenience sampling is appropriate when respondents are not easily accessible and the population size is not available or accurate. Respondents were asked various questions, but with regards to issues pertaining to affordable housing delivery, respondents were asked based on their current experience of the housing market, to tick the factors that hinder the delivery of affordable housing. The factors were measured on a five continuum scale: 5 denotes extremely often, and 1 denotes not often at all. The ranking of these factors was determined by mode and Average Relative Index (ARI). The index is based on the cumulative weighting of the initial frequency score of each of the roles. The factors were selected or modified from various literatures: [3, 5, 6, 17, 18, 19, 20, 21, 22] and the authors' experiences.

4. Findings and Interpretations

4.1. *Respondents' profiles*

The academic backgrounds of the respondents are followed: estate management (42.3%), architecture (24.4%), quantity surveying (17.9%), engineering (11.5%), laws (2.5%) and 1.3% of the town planning. Also, 43.6%, 37.2%, 14.1%, 3.9% and 1.3% of the respondents are members of The Nigerian Institution of Estate Surveyors and Valuers; The Nigerian Institute of Architects; The Nigerian Society of Engineers; The Nigerian Bar Association and Nigeria Real Estate Developers Association of Nigeria respectively. In terms of working experience, respondents with less than five years working experience were 17%; 5 years to less than 10 years were 45%; 10 years to less than 15 years were 30%; 15 years to less than 20 years were 15% and those with 20 years and above are 4%. The interpretations of these statistics are that the surveyed respondents have the require knowledge, skill and expertise to provide valid explain to the nature, characteristics and issue pertaining to the Nigerian housing market.

4.2. *Analysis of factors hindering affordable housing delivery*

To measure the strength and validity of the factors, reliability and validity tests were conducted and the results are contained in Table 2. As shown, the data are both reliable and valid. Furthermore, to measure whether the factors are related to toward an aim or objective, both KMO and Bartlett's Test were computed (Table 1). The results return an excellent Bartlett's (0.000) signifying that the factors are highly related. However, as observed with the KMO results, there is evidence of correlation with some of the factors. In other words, some of the factors could be measuring the same causes. However, for an exploratory study, the results are acceptable. Summarily, these factors can be carefully coached towards developing a housing governance framework.

Table 1. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.454
Bartlett's Test of Sphericity	Approx. Chi-Square	2842.867
	df	1596.000
	Sig.	0.000

a. Based on correlations

The lowest factor measured 75% and the highest factors measured 92% (Table 2). To interpret, all the factors contribute in one way or the other to the problems leading to the housing shortage. Factor analysis was performed to cluster the factors for meaningful interpretations. The results of the principal component analysis (with Varimax with Kaiser Normalisation) using eigenvalue and factor loading of 1.0 and 04 shows that the total variance explained for the components account for 76%. The analysis produced 18 components as the main broad factors that determine the success or failure of any initiative towards affordable housing supply. More specifically, those factors underpin the components of the affordable housing governance. Based on careful examination the factors are further classified into: sectoral factors (factors related to the construction sector), regulatory and polices factors, legal factors, market factors, individual factors (demand side factors), nature factors (i.e. population) and economic factors.

Table 2. Distribution of determinants of housing supply.

Factor	V	R	1	2	3	4	5	Weightage	Rank
Lack of construction management skills	0.71	0.909	2	0	6	11	59	0.921	1
Harsh housing regulatory/legal framework	0.771	0.909	0	1	6	25	46	0.897	2
High interest rate on mortgage	0.823	0.907	0	2	7	21	48	0.895	3
Poorly configured vocational training for the construction professional	0.819	0.907	0	3	6	20	49	0.895	4
Lack of appropriate pricing mechanisms	0.779	0.908	0	2	7	21	48	0.895	5
Sub-standard materials	0.809	0.907	0	4	6	20	48	0.887	6
Nonconformance to design specifications	0.704	0.908	1	0	8	24	45	0.887	7
Lack of effective implementations of the housing policies	0.862	0.908	0	1	9	23	45	0.887	8
Lack of continuity in government policies	0.77	0.909	0	4	6	21	47	0.885	9
Poor consideration of sustainability in housing delivery	0.849	0.909	0	0	6	33	39	0.885	10
Substandard quality of housing units	0.796	0.909	0	2	8	24	44	0.882	11
Low household income	0.773	0.909	0	2	7	28	41	0.877	12
Unqualified workforce	0.789	0.909	0	3	6	27	42	0.877	13
Lack of access to long term funding for affordable housing	0.76	0.908	0	2	7	28	41	0.877	14
Failure or non-implementation of construction standards	0.797	0.907	0	3	5	30	40	0.874	15
Inadequate measure of the resettlement of those affected by right of way and similar requirements	0.802	0.908	2	1	8	24	43	0.869	16
Construction methods	0.863	0.908	0	4	4	31	39	0.869	17
Inappropriate use of materials and methods	0.679	0.907	0	2	11	24	41	0.867	18
Lack of database for the construction professionals	0.703	0.906	0	3	12	20	43	0.864	19
Too much attention high housing priced housing	0.794	0.908	2	1	7	28	40	0.864	20
High costs in title and property registration	0.797	0.907	0	3	7	30	38	0.864	21
"privitising" the provision of the housing subsector by the government	0.816	0.908	0	0	8	38	32	0.862	22
Land acquisition uncertainty	0.751	0.908	1	3	9	24	41	0.859	23
Procurement methods	0.783	0.907	1	2	9	27	39	0.859	24
Importers fixing prices of construction materials and components arbitrary	0.75	0.909	0	4	9	25	40	0.859	25

Table 2. Distribution of determinants of housing supply (Cont'd).

Factor	V	R	1	2	3	4	5	Weightage	Rank
Importers fixing prices of construction materials and components arbitrary	0.75	0.909	0	4	9	25	40	0.859	25
The appropriate size and mix of housing development for the community at large	0.745	0.907	0	2	8	33	35	0.859	26
Short mortgage tenure (usually less than 15 years)	0.835	0.908	1	2	9	27	39	0.859	27
Unsustainable home price appreciation	0.80	0.907	0	5	8	25	40	0.856	29
Lack of database for artisans	0.855	0.906	0	4	12	20	42	0.856	30
Too many unregulated agents in purchase of building materials	0.855	0.908	1	4	6	28	39	0.856	31
Low quality control	0.739	0.907	1	2	8	31	36	0.854	32
Excessive down payment	0.787	0.907	0	5	8	26	39	0.854	33
Late delivery	0.705	0.908	0	2	13	27	36	0.849	34
Fragmented housing policies	0.802	0.908	0	3	16	18	41	0.849	35
Lack opportunities for employment in the neighbourhoods	0.719	0.907	0	3	9	31	34	0.849	36
Increase in population	0.839	0.909	0	4	12	24	38	0.846	37
Lack of sufficient funding for developers	0.789	0.907	1	1	12	30	34	0.844	38
Poor maintenance culture	0.731	0.907	0	1	10	28	39	0.841	38
Low compliance to regulatory and environmental laws	0.83	0.908	0	6	7	30	35	0.841	40
Land ownership problems	0.805	0.907	0	5	14	21	38	0.836	41
High rate of urbanisations	0.827	0.908	2	2	15	20	39	0.836	42
The law on foreclosure	0.855	0.909	1	2	17	20	38	0.836	43
Cost of importing building materials	0.809	0.909	1	3	14	24	36	0.833	44
Poor social integration	0.774	0.906	0	10	9	19	40	0.828	45
Absence of issuance of certificate of completion and certification	0.837	0.907	0	9	9	25	35	0.821	46
Poor financing methods	0.816	0.909	2	6	6	33	31	0.818	47
Shortages of materials	0.907	0.907	2	7	12	19	38	0.815	48
Poor infrastructures- [road, water, electricity, telephone, etc.]	0.769	0.909	0	9	10	25	34	0.815	49
Lack of recreational facilities in the neighbourhoods	0.824	0.908	0	10	13	18	37	0.810	50
Restrictions on the amount paid in subsidy to low-income households to encourage incentives to work	0.822	0.906	1	5	20	18	34	0.803	51
Inappropriate standards	0.75	0.906	0	4	23	20	31	0.800	52
Non-payment of housing loans	0.80	0.909	3	7	8	29	31	0.800	53
Low awareness on alternative source of funding and procedure for obtaining foreign loans	0.782	0.909	0	7	18	21	32	0.800	54
Too many speculators	0.851	0.908	4	9	4	29	32	0.795	55
Cultural issues	0.796	0.906	1	11	12	20	34	0.792	56
Duplication of roles between state and federal regulatory bodies	0.878	0.907	0	11	19	17	31	0.774	57
Documentations	0.774	0.911	8	7	8	29	26	0.749	58

R= reliability; V= Validity

The interpretation of the results is complex. In particular, the construction sector related factors are dominants. Though this is contrary to our expectation, but it is not surprising. The plausible interpretation is related to the poor performance of the construction sector. An overview of the performance of the construction was demonstrated earlier in the manuscript.

5. Concluding comments

This paper has reported a study that identified and categorised the main causes leading to housing shortages. Each of the causes produces significant impacts in the housing shortage. The combination of all the causes created the housing crisis that is widening and if not address together urgently would lead to a more severe crisis. To ensure the continued supply of affordable housing, there is a need for rethinking on the delivery strategy. A new strategy for providing affordable that involves the key stakeholders from the demand and supply is needed. ‘Housing governance’ can help matching together the various interest groups in the decision making. At the moment, the government will have to play multiple roles of providing an enabling environment for the housing market and effective and continues housing provision. The housing market is not mature yet, for the government to shift its roles totally to that of enabler only. In the developing countries, housing is often funded by the private individual, whereas in the developed countries, it is generally funded by the developers. The government also provides a substantial part of the housing, through partnerships with housing developers, and housing associations or providing loans to the private owners or housing associations that meet certain criteria. However, it should be noted, that the main concerns of the study that this study forms part of is to develop a housing governance, therefore, further studies are required to explore the other part of the research. These include the operations of the housing finance market and the requirements of the home owners.

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Market analysis of housing shortages in Malaysia

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Abstract

The cost of accommodation continues to increase despite various government measures in the form of taxes and subsidies. While the market is the most efficient way to allocate resources, to determine housing price, the capital market for housing have very weak mechanism that if left unregulated will be ineffective and inefficient, because the choice may not be the best for the society as a whole. This study is based on literature review and a case study. The case study involved one of the affordable housing schemes in Malaysia. The study demonstrates that to base affordable housing price on market prices are seriously deficient in that it ignore the basic essence of affordable housing provision. There is no real basis for economists' strongly held believe that house prices must be determined by the market to be efficient. The study shows that government can intervene in affordable housing market in various ways to increase homeownership rate.

Keywords: Tax, subsidy, market price, affordable housing, rent ceiling, social interest.

1. Introduction

A market is defined as a situation or arrangement that brings buyers and sellers into a close contact to exchange goods or services. In the market, the price paid for a good or service is determined by the supply and demand forces. Specifically, a market aims to allocate resources and to maximise the welfare of buyers and sellers. With the market structure, a buyer will not ordinarily pay more than the value of the good or service 'earned'. On the other hand, the market allows sellers to make 'rational' profit. The rational choice thinking is well grounded in the mainstream economics principle. Yet, even though the market is considered as the most effective way of allocating resources, it sometimes fails because of factors like price, income distribution and quantity regulation, taxes, subsidies, externalities, public goods, social interests, common resources, monopoly, and high costs of the transaction. In other words, the market mechanisms could also lead to inefficiency [1]. Market failure occurs because of under- or over-production. It is a situation where the market does not achieve 'economic efficiency' due to delivery of 'inefficient outcomes'.

Alternative methods (such as first-come-first-served basis, majority rules, context, lottery, personal characteristics, and force) could sometimes prove to be more efficient. In fact, there is no single mechanism – including the market – that allocates all resources efficiently [2]. Housing is a major industry where price mechanisms or market regulations are applied for efficiency. However, because of income distribution, housing provisions are often controlled by governments. The private sector argues against government controls, based on what some economists say. They contend that not allowing the market to allocate housing would create scarcity, increasing both rental costs, encourage black market, search activity, reduce productivity and cost of ownership. But like education and health, housing is an investment and not consumption. Since the supply of affordable

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housing is mainly in the public interest, it takes into consideration the society as an entity. For instance, housing is a measure of quality of life. For the pensioners or retirees, housing is to them a security issue. For instance, a country with adequate housing would spend less on the preventions and controls of diseases, security, rehabilitation homes, and enhancement in social integration and economic prosperity. Not surprisingly, housing price /rent is a political issue. The market capitalisation for housing has a weak mechanism that, if not regulated, is likely to be ineffective and inefficient. However, to invest in housing provision requires households to have funds. This is where the role of government in the market is crucial. The government can fill these gaps in a number of ways, including providing housing directly, providing funding without houses, or both. The role of government is therefore multiple or triple. Governments fill these gaps by providing subsidies, incentives, loans, lands, to both developers and homebuyers.

From the mainstream economists' perspective, the market is able to reduce both shortage and surplus in the housing market through price mechanism; without government intervention. But unfortunately this theory has not worked and neither will the shortage in the housing supply go away if the economic theory only is considered. The immediate question therefore is why is the market unable to correct the housing shortages [and surplus in some cases due to poor distribution]? Or can it? Again, the immediate answer is that affordable housing is a market failure; therefore, government has to intervene. Government intervenes in housing allocation through the rent ceiling to control prices of houses especially for certain members of the society. Primarily, this based on income and house price. Therefore, government sets a rent ceiling below equilibrium price to increase access to homeowners. But this contradicts the principles in the mainstream economics. In market failure situation, equilibrium does not exist. Public goods represent a kind of market failure. That is, the quantity demand and supply does not reconcile each other. Therefore, issue in market failure required critical examinations in the efforts to proffer solution to housing shortages. Knowing how the housing market operates will enhance understanding to provide some solutions. However, it does not imply that the solution resides only within the market, but government policies are also required. Hence, the questions that required intermediate answers include; how does government formulate the policies on housing supply, how does the government regulate housing supply, what are the objectives of the government policies on affordable housing supply, what are the applicable instruments. The examples of government instruments include regulations, incentive mechanism. However, in this current study, focused is directed to highlight the housing shortage and to provide through an exemplar case study, what happen when government intervene in housing provision. The selection criterion for the selection of the case study was a developer using one of the government affordable housing schemes in her housing development.

2. Research design

Research can be conducted through different methods, but what determining the 'best' method' are the purposes of the research guarded in terms of aim, and objectives, questions and hypothesis. For this purpose, research could be based on the survey, experimental, simulation and some are based on literature review. Similarly, research methods could be described as cross-sectional or longitudinal approach. Research that involves data collection on sites is described as primary research, while research that involves analysis and scrutiny of processed data is described as secondary research. Secondary research hinges on data processed from primary research. Various researchers, including Church [3], have discussed the usefulness of secondary data in research. The present research combined both primary and secondary research. The secondary research used data sourced from the Department of Statistics Malaysia, Economic Planning Unit, Bank Negara/Central Bank of Malaysia, CIDB Malaysia, and Ministry of Finance Malaysia to explain the housing shortages in Malaysia. Data are analysed using IBM SPSS Statistics/PAWS Statistics. The primary research in this study was based on a case study of a developer that specialises in affordable housing. The case study represents an exemplar affordable housing scheme. The case study involved the MyHome Scheme. The cost of MyHome in the cities is RM300, 000. Though there is a RM30,000 discount for first time buyers. The case study involved the descriptions of the operations of a developer that applied the MyHome scheme in her affordable housing supply. The scheme is controlled by the Ministry of Urban Wellbeing, Housing and Local Government. The primary purpose of the scheme is to stimulate private sector investment in the construction of low and medium cost houses. It is one the initiative introduced by the government to help Malaysian own their first home. Under this scheme, RM30,000 subsidy is offered for each unit to the developers. While the developers can select the location for the construction, government gives priority to developers that built the houses in the areas of high demand. The scheme has two plans. Plan 1 has built up area 800 square feet, with 3 bedrooms and 2 bathrooms, with the market price of RM80, 000- RM120, 000. Plan 2 has built up area of 850 square feet comprising with 3 bedrooms and 2 bathrooms, with the market price of RM90, 001- RM170, 000. For the plan1, for home buyers to qualify, the household monthly income should be between RM3, 000 RM4, 000 while for plan 2, the household monthly incomes are fixed at RM4, 001 to RM6, 000. The case study is centered on a leading property developer in affordable housing market that recently (around 3rd

quarter of 2015) launched its first phase of the affordable home production. The first phase comprises of 186 units of single storey terrace units with a built up area of 850 square feet with leasehold price ranges from RM180, 000 to RM200, 000 per units.

3. Theoretical framework

The need for housing in Malaysia is expected to increase remarkably due to rapid growth in population, interstate migration, changing economic status of citizens, changes in tastes, and dilapidation of existing housing stock. At 2020, the population of Malaysia is estimated to reach 32.4 million. While the need for poor and low-cost housing will continue, the emphasis of supply will be shifted to delivering vibrant housing that is commensurate with the country's status. The Malaysian housing market is very volatile. To illustrate this, Figure 1 graphs changes in the volume and value of property transactions over the last 24 years. Due to large variations in number of transactions, the data are presented in an index forms. The average change in volume is 114, while the average change is the value of the property is 292 for the recorded period, indicating that price gained strength despite government controls of price and speculation. In 1990, the volume of property transactions was 148.20 (equivalent to RM15.16 billion); however, in 2014 this has increased to 384.06 (equivalent to some RM163 billion). This represents an expansion of 88% *[This is calculated based on the midpoint formula]* in volume and 166% *[This is calculated based on the midpoint formula]* in monetary terms. The sharp drop in housing market activity in 1998 is a result of the financial crisis that affected all Asian countries including Malaysia. While there was a recovery towards 1999, it falls two years in 2003. The drop in 2009 also coincides with the 2008-2009 global economic meltdowns whose major reason was the collapse of the housing market in the USA from 2007 through 2009. The global economic meltdowns led to a decrease in GDP, and an increase in unemployment, which consequently disrupted international trade and financial markets. It also hampered lending by banks.

Table 1: Volume and Value of Residential transaction by year 2001-2014

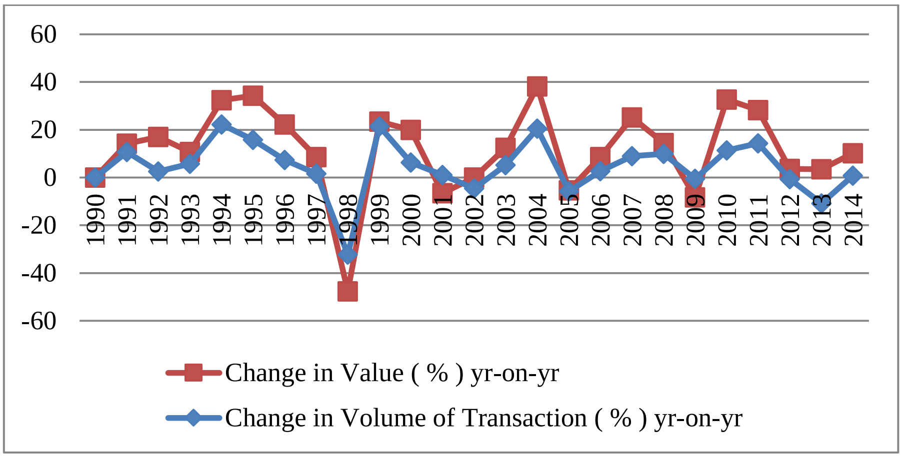

Figure 1: Annual Change in Volume and Value of Property Transaction 1990 – 2014 [4]

Property is transacted in five broad sectors, namely; residential, agricultural, development, industrial, and commercial. In terms of volume, the residential segment accounts for about 80%, and in terms of value of transactions, it averages 50%. The total value of residential property transacted has grown significantly since 2009; and for 2014, exceeded the pre-crash level peak of 2005. While this trend is most likely to continue, perhaps the soar is due to government policies on home finances and increase in ownership. However, it is apparent from the house index that residential property prices have risen significantly in recent years (Figure 2).

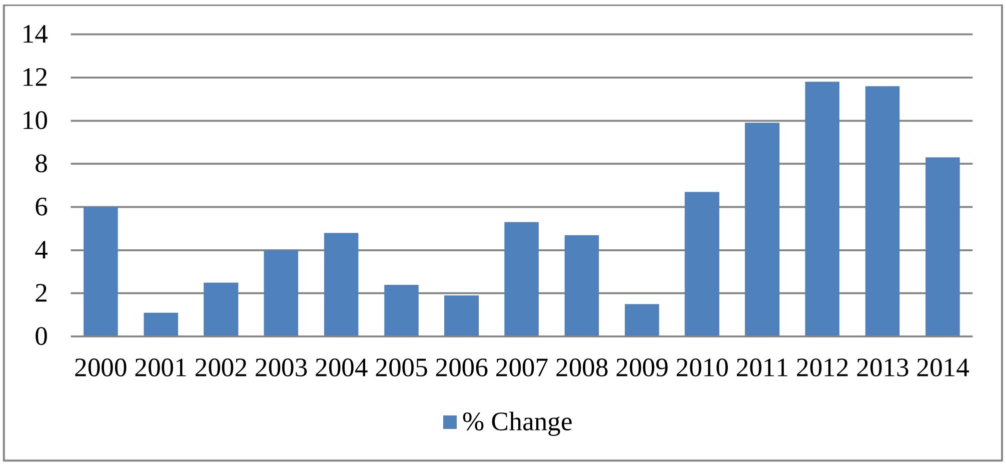

Figure 2: The Malaysian House Price Index. [5]

Statistics show that Malaysia has 4,831,791 residential units representing an increase of 2.2% from 4,725,109 in 2013. That is, the production of units is approximately 107,000 per annum. With a population of 31 million, there are approximately six persons per home. This also means that there is a supply of four units per 1000 population annually. This statistic indicates that there is home shortage about 12 million units. The government has launched various schemes to increase home-ownership among Malaysians (e.g. MyHome / Skim Rumah Pertamaku (SRP), Perumahan Rakyat 1Malaysia (PR1MA), Rumah Mesra Rakyat (RMR1M), Program Rumah Mampu Milik (RMM), Program Penyelenggaraan 1Malaysia (TP1M), Housing Loan Scheme, People's Housing Program, and Rumah Transit/ transit house programme. There are prequalification criteria for each of the schemes for the homeowners. However, home-ownership was 63% in 2000; this dropped to 55% in 2010 [6]. To interpret, there is an annual decline of about 1% in home-ownership. Home-ownership will thus be less than 50% in 2020.

Benchmarked against international standards, housing in Malaysia is not affordable despite government measures [7]. For illustration, the cumulative monthly expenditure on rental for all Malaysians is close to 27% of household income [4]. However, for those in low and middle-income groups, it is 35% [8]. In fact, the 2014 inflation in housing, water, electricity, gas, and other fuels categories increased to 3.4% (2013: 1.7%), reflecting upward adjustment in electricity tariffs and a broad-based increase in rentals across different types of residential property [9]. Mean income in Malaysia is RM6, 141. However, median income (which is a more acceptable criterion to measure affordability) is RM4, 585 [12]. This makes Malaysians spend more of their income on housing than on any other goods and services. Those that earn the median incomes are the typical family in the society living in a national median-priced single-family home. This housing affordability index (or HAI) provides a method to discover whether housing is more or less affordable for ‘standard family’. The index takes into account the determinants of housing affordability to those earn the median incomes. These include housing prices, location, mortgage rate, family size, interest rates, and household income. The affordable housing price elasticity of demand is relatively elastic ($-1 < Ed < 1$), because the percentage change in quantity of housing demanded is greater than that of the housing price. Hence, when the price of affordable housing is raised, the total revenue decreases, and vice versa. The increasing in wages and salaries of those in low and medium has done little to cushion their housing cost burden. Primarily because, as income increase costs of other goods and, services like, utilities, transportation, cost of education and medical bill also increases in tandem. The ratio of household debt to GDP is 87.9% (RM940.6 billion), but residential housing loans constituted only 46% (RM430 billion) of total household debt. A descriptive treatment of the housing shortage in Malaysia is found in [10]

A housing market is a collection of people and firms who trade in housing. Most housing markets have many buyers and sellers, and are competitive. As in other competitive markets, prices for houses are mainly determined by supply and demand. The market has a fundamental role in the allocation of housing; it provides a strong incentive for the supply side. When the market incentive is strong, a developer will supply more houses; because to the developer, what the market reward is valuable they can make more profits. In general, two types of market forms are available for housing markets: a competitive housing market, and a regulated housing market. The market is regulated when the government does not allow house allocation based on the market forces. Governments both in developed and developing countries set a rent ceiling to protect those in the low and medium income groups.

For instance, in Malaysia, to cushions the housing shortage, the government responds with initiatives such as the establishment of the National Housing Council (NHC) in 2014 and schemes. The purpose of the council was to develop strategies and action plans, and to coordinate legal aspects and property price mechanisms in ensuring the provision of affordable and quality housing. A fundamental feature of government efforts with the council and the schemes is the provision of incentives to developers and/or homebuyers. If the housing market is not regulated, the supply side will continue to benefit before the marginal cost increases. In many cases, however, what the market rewards is not valuable to the society. Factors of production can also be allocated on the basis of lottery, price description, and majority rule. In all situations, there is a trade-off. Sometimes, when market failure occurs, it means either too much or too little of a good or a service was supplied by the market. In the housing markets, developers influence supply, which introduces elements of monopoly on the supply side. Perhaps using means of allocation other than the market would provide weak incentives to developers. A regulated housing market could, however, be good. Housing control has been a major type of government regulation all over the world for a long time.

Economists (specifically, private developers), however, believe that a regulated housing delivery leads to housing shortage and with its attendance consequences. Figure 3 through an exemplar case study maps what happen to the housing market if price is not traded on the competitive market. The figure is based on the MyHome scheme with housing market price of RM200, 000. In the affordable housing market, a developer is willing to supply 60 units at the price of RM300, 000 for a unit comprising 3 bedroom and 2 bathrooms; that is at the equilibrium price and quantity, "E". However, supposing the government decides to impose a ceiling price of RM250, 000 at point "k", the contractors will be unable to meet the current supply of 60 units. Rather, they will only supply 48 units at the ceiling price. As there is a ceiling price of RM250, 000, the resultant will be points "j" and "g". (This is currently the case. The government is imposing a ceiling on housing units to allow those in low and medium-income groups to have access to homes. Initiatives like PR1MA are based on the same principle. Thus, a shortage will arise; and as shortage arises, homeowners vying for the 48th unit will pay at least RM360, 000, because it will then be traded on the black market and cost of search activity.

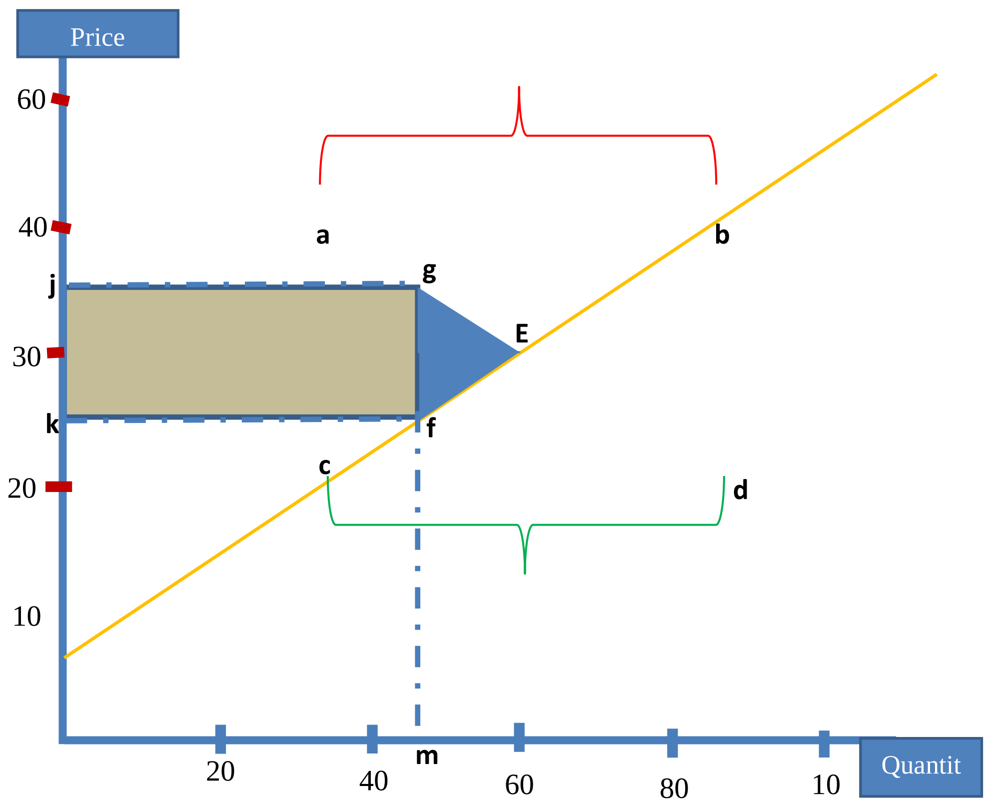

Figure 3: Effect of regulation on housing price and quantity supply

Presented above is a graphical illustration of the affordable housing market operation. Perhaps, in the mainstream economics, there is no argument to this illustration. This will always be the case in a market economy. This scheme is not efficient based on the economic principle of rational thinking. But as argued earlier, housing and affordable housing operations, in particular require government interventions to be 'efficient'. Efficiency in this context may be construed in terms of social benefit. In this study, it is not argued that some of inefficiencies do not exist if government perform multiple roles of providing housing directly and providing the enabling environment for the private sector to provide houses based on demand and supply forces, but what is argued, is that, in actual fact, none of the methods of allocating resources is efficient in allocating resources at all time. Here, it is the effective combination of any of the methods after careful analysis of the stakeholder requirements that is should be preferred. Many researchers or specifically, economists agreed that, it is not the functions of the government to provide housing, because it would lead to long term-liabilities and since the government will not be able to provide adequate homes to those that do not have the finance requisite to own or rent their homes [11]. Furthermore, to the extent that there is no cogent relations between housing affordability and property value, [12] the argument that rent control will lead to housing shortage weak.The adequacy and affordable of housing is a global priority. There is a strong relationship between quality of houses in the country and the economic development. The relationship between adequate housing and national productivity is very strong and positive and these are well documented. A country with adequate housing also means that such country would spend less on the preventions and controls of diseases, has reduced in crime rate and enhancement in social integration. A poorly maintains housing is unsightly, irritating, and dangerous to use. Other benefits include lower energy use and improvement of sustainability criteria. In fact, for most or all around the world housing is a measure of quality of life. For the pensioners or retirees, housing is to them a security issue.

4. Concluding remarks

The structure of the Malaysian housing market is complex. If housing priced or rent is set above the equilibrium rent, it will not have any effect, since it will not be constrained by market forces. In this case, the force of law and the force of the market will be in conflict. The force of law will restrict the determination of rent by forces of demand and supply. As demonstrated above, if the government sets the rent ceiling below the equilibrium price, it will lead to shortages and increase in rent. In a competitive market, developers are able to maximise profits by influencing the housing supply and price. They advise the government in providing incentives and/or increasing subsidies to house buyers or to developers. They also advise the government to reduce taxes on construction materials and to relax regulations on migrant labour. They encourage banks to lower interest rates on mortgages. A developer association, as an organised group of housing developers, influences housing prices and rents. Like other private organisations, they are profit-driven; they aim to influence the supply, price, rents, and other conditions of housing delivery. Affordable housing delivery is also considered as a mean of alleviating poverty. Furthermore, investment in affordable housing is a necessity for economic growth and can be used to address both environmental and social problems.

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Arrangement of Material Depots at Construction Site by Using Continuous Conditions

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Abstract

In this paper, we are introducing a model for optimizing the arrangement of final material depots at a construction site that uses continuous conditions. The target is to minimize the construction time, cost and resources by minimizing the delivery distances. In this model, the feasible positions of the material can be used in a continuous or discrete way as the known models do, but the structures are used in a continuous way. A simple example demonstrates that the product can be modeled as a group of 2D elements (lines, curves) with third dimensional information and the calculated result is compared with an expert's solution. The usability and the further generalization of the model are declared. It needs less input data than the discrete model does so it can be an alternative model to the discrete model if the number of the units that build up the structure is large or unknown.

Keywords: construction site layout planning, continuous demand, facility location allocation

1. Introduction

One of the preliminary processes in the construction management is planning the construction process. Part of the construction planning process is *construction site layout planning (CSLP)*, in which space, time, material, labour, money and equipment are recognised as resources [1, 2]. The target of CSLP is to minimise construction time, cost or required resources. Due to CSLP has significant impact on the productivity, cost, time, safety and security, several site layout planning models have been developed in the past decades. These were collected in an overview [3]. These models use the space in three different ways: *predetermined location, grid system, continuous site space*. The space types were clustered to five groups like *total space, product space, installation space, available space and required space* [2]. A partial task of the *construction site layout planning* (CSLP) is the allocation of construction objects on site. In practice, the construction objects allocation is carried out routinely [4] based on human judgment using the first-come-first-served method [5] or using the construction manager's experience [6]. Due to the number of factors that are involved in the CSLP, computers were identified as an efficient tool for solving the problem, such as computer-aided systems that are CAD-based [7], AI techniques used [8] or genetic algorithms used [9, 10, 11, 12, 13]. The objects, the structure and the spaces are continuously adjusted at different phases of the construction project. Therefore, researchers have developed dynamic site planning methods as well, like max-min ant system etc. [14] or BIM-based models [15]. Most of the developed models identify the number and the size of the temporary facilities that serve the construction site, and then search for the optimal arrangement by *minimizing the total transportation costs* between the facilities or from facility to the structure to be built:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{m} d_{ij} R_{ij} \tag{1}$$

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in where n is the total number of construction objects; m is the total number of constraining objects; d_{ij} is the travelling distance from the location of the construction object i to its ideal location concerning the constraining object j; R_{ij} ($R_{ij} \in Q$) is the parameter that represents transportation cost or the weight of constraint between construction objects i and constraining object j [7]. The travelling distances can be calculated by using either Euclidean distance or rectilinear distance.
The root of the CSLP problem is known as *k-median problem* in the operation research literature as a part of the *location allocation problem (LAP)*, where the demand is understood as the structure that needs to be built, the density is readable as the volume of the structure and the facility is readable as the material depot. If the number of facilities (***k***) is one, the problem is known as the *classical Fermat-Weber problem (1929)* [16]. In the CSLP models the number $k \geq 1$ the facilities' location can be calculated in discrete form by dividing the site into a given grid-based set of feasible location points and dividing the structures into unit areas or even in a continuous way using genetic algorithms or other artificial intelligence because of the infinite number of possibilities. Most of the LAP literature is based on discrete demand [17] like the known models of the CSLP where the target is to define the site objects' space and shape by using a collection of unit areas. In this paper, a model is presented for the *k-median problem* that uses the structures as continuous demand as line segments (as these were provided by the architect and engineers in their CAD drawings) and searches for the optimal arrangement on the entire XY plane.

2. Assumptions and objective functions

Architects and engineers define most structures with 3D CAD elements. The structures are represented by 2D marking with the Z directional information included on the drawings. Some structures are marked by symbols (e.g. pillars or windows), some are marked by line segments or curves (e.g. wall tiling) and some are marked by areas (e.g. floor tiling, concrete slabs or the boarding of the slab formwork). The material, size, volume and exact location of the structure are given in the architectural documentation in advance. In this paper the presented problem is very similar to the problem studied in an earlier paper of the authors [18] just here we deal with the structures that are marked as line segments instead of the areas. The structure is modelled as a two-dimensional figure denoted by the end points ($\boldsymbol{A_i}$) of the line segments.

2.1. *Assumption 1.*

The structures are marked by a group of line segments. The line segments that belong to a depot must look like a line segment-chain. A group of line segments consists of $\boldsymbol{k}$ pieces of line segment-chains. A line segment-chain consists of $\boldsymbol{l}$ pieces of line segments where the end point of each line segment is the beginning point of the next one that has a volume $\boldsymbol{W}>0$ if it is possible. Each line segment piece is defined in advance by its endpoints $\boldsymbol{A_i(x,y)}$, ($i=1\ldots m$, $m\in N$) and each line segment piece has a $\boldsymbol{W_i}$ volume that represents the Z directional volume of the structure $\boldsymbol{V_s}$.

2.2. *Assumption 2.*

The material laydown is denominated as the final material depot from where the material is delivered to the structure in units. The final material depots are represented by the projection of their centre of gravity ***S (x, y)*** to the ***XY*** plane. One type of material depot usually consists of a certain number of material elements resulting in equal material depot volumes $\boldsymbol{V_d}$. The number of the required depots ($\boldsymbol{k}$, $k\in N$) can be easily calculated by dividing the volume of the structure by the volume of the final material depots. $k= V_s/ V_d$.

2.3. *Assumption 3.*

According to Moore [19] there are two basic methods to deal with the CSLP problem. One is placing some of everything everywhere (or in a couple of combinations) and picking the best from these. The other method that is used in this paper is by bringing objects in one by one in a certain order and calculating the optimal arrangement after each step [11]. The model deals with one type of material at a time.

2.4. *Assumption 4.*

The handling paths from a depot to each point of the served structure (to each point of the line segments) can be calculated by two ways: using **Euclidean distance** or the shortest path inside the feasible handling area. In this study we use and measure the Euclidean distance in an unusually way. The length of the total delivery path from a certain point to the structure is counted by the measure of the areas $\boldsymbol{(T_i)}$ that are defined by the modeled structure's

2D marking (Figure 1.a.) and the vertical projection of the marking to the envelope of the Euclidean cone, that is set into that certain point. In this case where the structure is marked by line segment *($A_iA_{(i+1)}$)* or curve and defined by its endpoints ***$A_i(x,y)$*** the total delivery path from a ***$S(a,b)$*** point to the structure is counted as areas (line integrals) as shown on Figure 1.b.

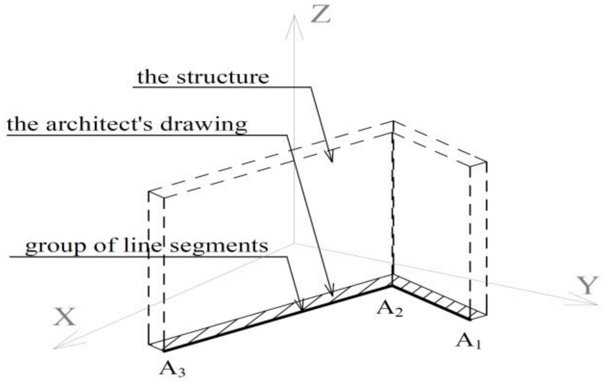


Figure 1.a. 2D marking of the structure

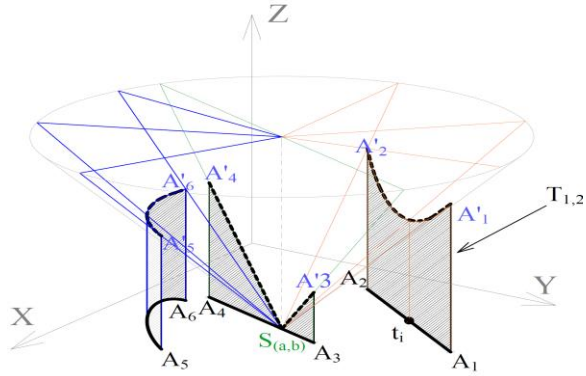


Figure 1.b. The length of the total delivery path

$$T_{i,i+1} = \int_{t_i}^{t_{i+1}} \left(|a-x|^2 + |b-y|^2 \right)^{1/2} d\varphi \tag{2}$$

Where ***T*** represents the size of the area bounded by the 2D marking, the vertical projection of it onto the Euclidean cone, the ***$d\Phi$*** is an extremely small change in arc length of the curve, ***A_i'*** is the distance between A_i and S points,

2.5. *Objective function*

The objective is to find the allocation of the final material depots, where from the material can be handled by pieces to their built-in locations along the minimal length of paths. This model leaves out of consideration the delivery cost because the model assumes that all of the delivery paths are horizontal and the delivery cost is directly proportional to the length of the delivery path and brings in one type of object at a time. The target is to minimize the length of the total delivery path.

2.5.1. In the case of k=1

The line segment-chain is given and the minimization form can be solved by any kind of two-parameter minimization:

$$\min_{(a,b)} \sum_{1}^{l} \left[W_{(t_i,t_{i+1})} \int_{t_i}^{t_{i+1}} \left(|a_K - x|^2 + |b_K - y|^2 \right)^{1/2} d\varphi \right] \tag{3}$$

2.5.2. In the case of k>1

There are infinite solutions because the start points and the end points of each line segment-chains are unknown. If any point of the line segment-group is renamed as cut-point (***C***) for dividing the structure to unique volume *k* pieces of line segment-chains, then each of the line segment-chains is defined and the minimum of the sum of the delivery paths (areas) for that certain cut-point can be calculated. The minimization form for the case of *k*>1 and cut-point is defined is:

$$\min_{C} \sum_{1}^{k} \min_{(a,b)} \sum_{1}^{l} \left[W_{(t_j,t_{j+1})} \int_{t_j}^{t_{j+1}} \left(|a_K - x|^2 + |b_K - y|^2 \right)^{1/2} d\varphi \right] \tag{4}$$

In where ***C***$\in(A_i,A_{i+1})$ is the cut-point for dividing the group of line segments to line segment-chains, ***E_K***$\in(A_i,A_{i+1})$ is the end point of each line segment-chain, ***k*** (k$\in$N) is the number of the needed depots; ***l*** (l$\in$N) is the number of line segments that belong to the certain depot; ***$W_{(i,\,i+1)}$*** (W$\in$Q) is the *Z* directional volume of the line segment between A_i and A_{i+1} (defined by the volume of the structure); ***a_K*** and ***b_K*** is the ***x*** and ***y*** coordinate of the searched ***S_K*** depots on the entire XY plane.

The object is to find *C* for the global optimal arrangement. If we place C_i to each A_i and solve the equation *m* times each counting will give a minimum of the total delivery paths that belongs to *k* pieces of R_j points. If we place the cut-point anywhere on the line segment between R_j and R_{j+1}, the solution will be a member of a curve ***(f_R)*** that has one minimum or one maximum point. If the curve is concave then R_j or R_{j+1} will be the location of the cut-point for the local minimum solution between R_j and R_{j+1}. If the curve is convex, the minimization of the curve between R_j and R_{j+1} will give the location of the best cut-point and will result in the minimum of the total delivery.

The global minimum of the model is the lowest result of all the counted local minimums. This means the minimization has to be solved $2m$ times (m times for all A_j and m times for all the curves between R_j and R_{j+1}) to find the global minimum of the model.

3. Example

In this example the target is to find the optimal allocation of the final material depots ($S_{(a,b)}$) for the wall tiling work of a rectangular room (Figure 2.) from where the material units can be delivered to the structure along the minimal path.

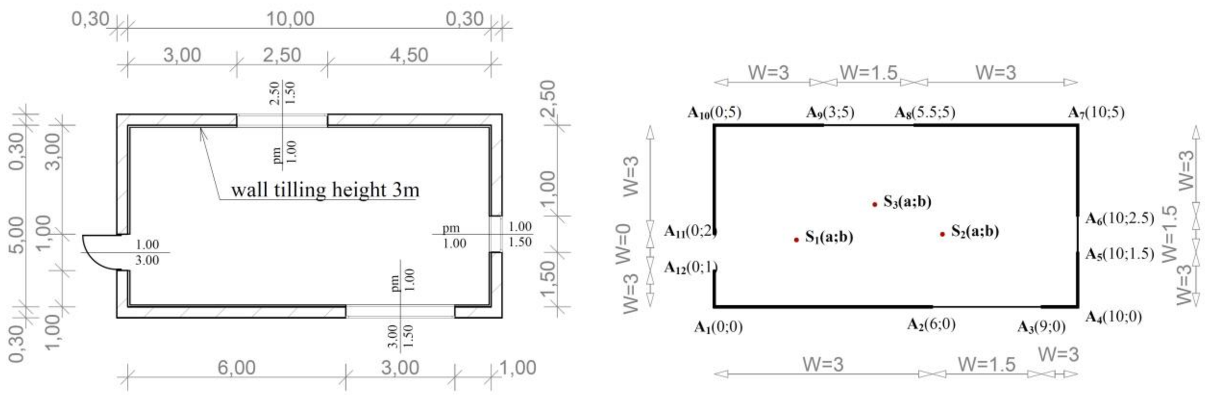


Figure 2.given drawing by the architect and the transformed information into the model

The volume of a material depot, the volume and the geometry of the tiling work with Z directional information is provided in advance (V_d, V_s, $A_i(x,y)$) (Figure 2). The number of the needed depots is calculated: $k= V_s/ V_d$.
V_s=3x(10+5+10+5)-(3x1,5)-(1x1,5)-(2,5x1,5)-(1x3)=77,25 m2; V_d=25,75 m2; $k= V_s/ V_d$=3 pieces
In this example x=t or y=t. At first all R_j has to be found by measuring counterclockwise k pieces V_d volume line segment-chains from all A_i and mark their coordinates. We have m=12 pieces A_i and we have (k-1)m=24 pieces E_{ik}.

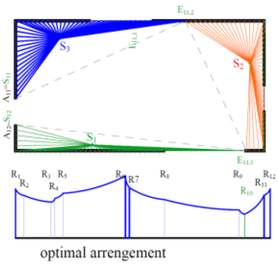
After all of the relevant points are found then the local minimums of the total delivery paths are counted by a program called *Mathematica 7* for each A_i as cut-points. The minimization form ran 12 times and gave the minimums of the sums of the total delivery path for all Rj (Table 1).

$$\sum_{1}^{k} \min_{(a,b)} \sum_{1}^{l} \left[W_{(t_j,t_{j+1})} \int_{t_j}^{t_{j+1}} \sqrt{|a_K - x|^2 + |b_K - y|^2}\, d\varphi \right] \tag{5}$$

In this case the optimal allocation of the depots belongs to the cut-point of $R_{10}=R_{11}=A_{10}=A_{11}$ as readable on Table 1. and shown on Figure 3.a.

4. Accuracy of the results

The architect drawing of this example was provided to a professional bricklayer. The expert was asked to mark the best arrangement of the three depots and the parts of the structure that he would serve from each depot for minimizing the total delivery path. His solution is shown on Figure 3.b. where the surfaces of the walls are turned to the *XY* plane and each color represents the surface of the structure part that he would serve from a certain depot. It is readable on Figure 3.c. that from the first depot (S_1) he would serve a bigger volume structure part than a depot volume is, and from the other two depots (S_2, S_3) he would serve smaller volume structure parts. Based on the technology itself and the equal volume of depots the first depot will run out of the material before the tiling work is done, so he would need to deliver the material from the other two depots. With the expert's solution, the workers would deliver the materials a 69.91% longer path than was counted as the optimal arrangement shown on Table 1.



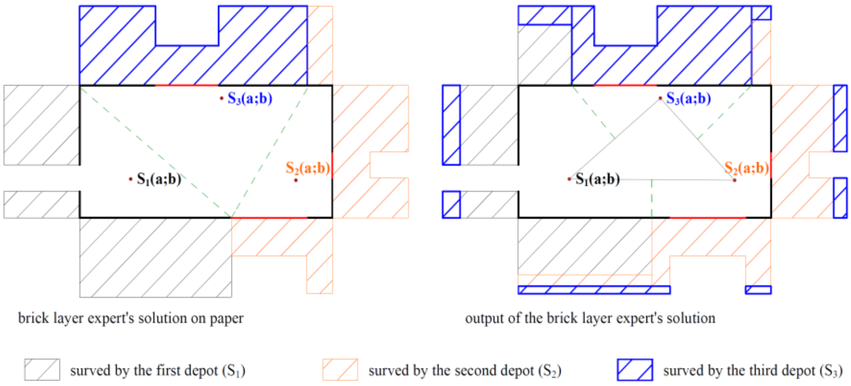


Figure 3.a. An the lowest solution of all counted equations

Figure 3.b-c. The expert's solution paper and in real

This 69.91% increment of the total delivery path is impressive if we declare that the increasing of the total delivery path by 7% causes a measureable raise in the total delivery time [20]. Based on this experiment, the searching for C to find the optimal arrangement is worth the time because the worst minimal solution for different cut-points (row R_6 on Table 1.) is 12.12% worse than the optimal arrangement (row R10 on Table 1.**)**. It must be recorded that the arrangement of the final material depots is not enough for minimizing the sum of total delivery path, the served structure parts are needed to be defined for each depots.

5. Generalization of the model and conclusion

In this example, the location of each depot was searched on the entire *XY* plane, but it could be localized into a certain place as *available space* [2]. This example was solved for a convex shaped structure and the model counted the lengths of the delivery paths by Euclidean distances, but it can deal with obstacles and concave structures in exactly the same way as the discrete model does by dividing the area up into areas named *'visible from', 'partly visible from' and 'not visible from'* [21]. In this example, the delivery cost was left out of consideration because the allocation of only one kind of material depots was searched for and the delivery paths were horizontal to every directions but this model can be integrated to the models that minimize the total delivery cost as well. It needs less input data than the discrete models do because it does not need the number and the exact places of the units that build up the structure. This model can be an alternative model to the discrete model even if the number of the units that build up the structure is large or unknown because in this case the required time for the calculation can be significantly less and the difference between the solution of these two models is negligible.

Table 1. The sum of the total delivery path for each R_i

R_i				Σ	S_k					
		$R_i(x)$	$R_i(y)$	Σ	$S_1(a)$	$S_1(b)$	$S_2(a)$	$S_2(b)$	$S_3(a)$	$S_3(b)$
R_1	A_1	0	0	**16,64**	4,29	0	9,25	4,125	1,002	4,339
R_2	$E_{8,1}$	0,33	0	**16,49**	0,811	4,161	4,625	0,001	9,054	4,316
R_3	$E_{5,2}$	1,42	0	**16,82**	8,384	4,736	0,392	3,521	5,696	0,023
R_4	$E_{9,1}$	1,58	0	**16,94**	0,357	3,418	5,853	0,033	8,273	4,778
R_5	$E_{6,2}$	1,92	0	**17,22**	8,033	4,848	0,308	3,199	6,334	0,082
R_6	*$E_{7,2}$*	*4,4*	*0*	***18,22***	*5,71*	*5*	*1,043*	*0,828*	*9,192*	*1,103*
R_7	$E_{10,1}$	4,58	0	**18,2**	1,136	0,727	9,278	1,204	5,54	5
R_8	A_2	6	0	**17,21**	9,708	2,359	2,91	4,967	2,014	0,209
R_9	A_3	9	0	**16,28**	9,672	3,454	1,668	4,75	3,219	0,016
R_{10}	**$E_{11,1}$**	**9,07**	**0**	**16,25**	**3,292**	**0,011**	**9,65**	**3,505**	**1,606**	**4,726**
R_{11}	**$E_{12,1}$**					same as R10				
R_{12}	A_4	10	0	**16,45**	9,293	4,077	1,049	4,379	4,21	0

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Success Factors of Export Financing under the Buyer’s Credit Scheme

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Abstract

Buyer’s credit is a very useful mode of exporting in international construction especially in relation to extensive infrastructure projects. Large projects usually require substantial amounts of liquidity provided by banks. Importers seldom have enough own resources to cover the entire capital expenditures, while only few exporters have the capacity to provide credits to their buyers. The concept usually requires the participation of financial institutions on the exporter’s as well as the importer’s side. Many contractors still fail in their exporting attempts at the very beginning, due to the shortage of experience in this matter. Based on the literature review, foregoing research and exploratory interviews with trade finance specialists, the list of seven factors contributing to a successful project execution under the buyer’s credit scheme was compiled. This research analyses and compares the perceptions of Czech and German export finance practitioners. Research findings were derived from their empirical evaluation collected through structured questionnaires. For the purposes of this research, quantitative methodology was adopted. The main objective of this study is to prioritize these factors, increase their understanding and provide a route map to exporters considering the application of this advanced financing scheme. The authors argue that there are only minor differences between the perceptions of Czech and German exporters.

Keywords: buyer’s credit, export financing, international construction, success factors.

1. Introduction

Many construction companies are searching for new possibilities of their expansion. The domestic market sometimes does not offer a sufficient scope of projects enabling them to sustain their growth. In many cases, the only remaining option is to penetrate new foreign developing territories with a promising revenue potential. Developing markets also represent substantial risks of various kinds such as political risks, currency risks, performance risks or territorial risks. These conditions are compensated by significantly higher profit margins, compared to projects in well-developed economies. Such a profit potential becomes the main motivation for foreign contractors to enter these markets. The buyer’s credit scheme has become a widely applied tool for entering developing markets, where investors do not have a chance to reach the financing of their projects locally. Despite the increasing number of projects executed under this concept, there are still many projects failing. The statistical background provided by the Berne Union [2] or ECAs (Export Credit Agencies) across the world demonstrate solid volumes of credit insurance claims being paid. On the other hand, an extensive number of projects were successfully delivered and export credits were paid back as scheduled, which can be deemed as a firm reference base for future projects which are supposed to be ECA-covered. The purpose of this study is to examine the key factors leading to the successful project execution under the buyer‘s credit export financing scheme through comparing the perceptions and attitudes of Czech and German practitioners gained via a questionnaire survey.

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As a result of the recent global economic crisis, many exporters and bankers have found themselves seeking state support for their international transactions. Such support exists in the form of export credit insurance and guarantees provided by national export credit agencies (ECAs) to support national exports [11]. The role of credit insurers has rapidly grown since mid-to-late 2008 when the crucial importance of trade finance and credit insurance to support international trade flows became apparent in the deteriorating global economic environment [8].

2. Previous research on success factors of export financing

There are several studies associated to construction exports and project success factors. Gale and Luo [5] conducted quantitative research on the factors affecting construction joint ventures in China. The perceptions of Chinese and foreign executives were compared. Success factors were prioritized according to the perceptions of both groups of respondents. The study concluded that there were no significant differences in the perceptions of both examined groups. One recent study [10] identified exporter's eight key success factors of project delivery under the export financing concept in construction. The qualitative approach was selected. The factors were gained through case study analysis and supplementary interviews. The authors also highlighted the crucial role of export and credit agencies in these structured export transactions. Another study proved that bringing project construction together with secured project financing results is the key success factor in developing markets which enables export-oriented firms to succeed in highly competitive international bids [9]. Recently, there were several studies conducted on the factors associated with success in exporting [4,6,12]. These empirical studies are bringing valuable findings about the exports of goods in the manufacturing segment and the improvements of models that investigate selected determinants of export performance. Babakhani and Haji [1] in their study prioritized important factors on boosting exports; the factors were gathered by using a brainstorming discussion. Among other findings, the important role of the government was discussed in terms of setting suitable regulations and providing subsidized credits and tax exemptions.

3. Methodology

The first qualitative part of this research was developed based on an extensive review of academic literature and the reviews of several case studies related to export financing under the buyer's credit scheme. In this study, the authors applied the outcomes of their former research on export finance [9,10]. A number of supplementary interviews with managers of construction firms and export finance specialists were conducted.

As a result, seven factors leading to successful project execution under the buyer's credit scheme were compiled. The identified success factors (variables) are:

1. Strategic character and political support of the whole project
2. Positive country risk classification based on OECD Consensus
3. Exporter's experience with export financing
4. Exporter's long-lasting track record and stability
5. High credibility of the foreign investor
6. Significant share of technologies and deliveries from domestic suppliers
7. Knowledge of the foreign market environment gained through smaller projects

3.1. *Questionnaire design*

The questionnaire was designed to prioritize the formerly identified critical success factors of export financing under the buyer's credit scheme for two groups of respondents based on their empirical evaluation. The parallel task was to compare and analyze the perceptions of these two groups. In order to prioritize the selected success factors and increase our level of understanding, the Likert [7] scale from one to five was applied. Each statement was structured in the following form *"...contributes to successful project execution under the buyer's credit scheme*". The statements were based on the expectation that Czech and German experts may have different opinions on the topic in view of their different perception, land specifics and cultural background in relation to export in the construction sector. Five ordered response levels are used, although many psychometricians advocate using seven or nine levels; see an empirical study [3]. For the purposes of this research, the respondents were asked to specify the level of their agreement with each statement on the symmetric agree-disagree scale ranging between 1 and 5, whereas 1 stands for strong disagreement with the statement and 5 stands for strong agreement with the statement. In order to increase our level of understanding, the respondents were enabled to write down their comments and reasoning to their evaluation, which became an additional and valuable source of qualitative data.

3.2. *Data collection*

The essential point of this research was the dutiful selection of its respondents. The main precondition for the respondent selection was their qualification and experience, leading to proper understanding of the topic, in order to make sure only qualified answers would be collected. The targeted group of the respondents consisted of top managers from renewed construction companies focused on exporting, structured export trade finance specialists, representatives of national ECAs and development banks. For each group, 50 respondents were addressed with an anonymous research questionnaire.

3.3. *Data analysis and hypothesis testing*

Data analysis was undertaken in MS-Excel for Windows. The hypotheses were calculated by using the two-tailed *t*-test. The two-tailed *t*-test is an alternative way of computing the statistical significance of a parameter inferred from a data set, in terms of the test statistics. At first, means, standard deviations and variances for both groups were calculated; hereafter all 7 variables were ranked in the descending order of importance. The two tailed *t*-test was executed in order to find out whether there are any statistically significant differences between the two different sets of observations (Czech and German respondents). By the application of the *t*-test, a deeper analysis of the two datasets was made and the differences between each of the seven variables were better examined. The significance level of 0.05 was selected for the test. The *t*-value was determined according to the results of the F-test, which was calculated beforehand.

For $F \leq F_{0,975}$ where H_0: $\sigma_1^2 = \sigma_2^2$, the following formula was applied:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{1}$$

For $F > F_{0,975}$ where H_0: $\sigma_1^2 \neq \sigma_2^2$, the following formula was applied:

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{2}$$

4. Results

Out of 50 questionnaires sent to Czech or German respondents, a total of 39 or 36 fully filled in questionnaires returned. The response rate thus equals the excellent 78% and 72% respectively. Such a high response rate can be attributed to the active personal involvement of the researchers as well as to close professional connections to some of them. Several respondents asked additional questions to make sure they fully understood the topic. Many respondents also took advantage of the possibility of writing comments on single statements and their evaluation. This frequently helped the authors to better understand the reasoning of some respondents, which simultaneously had a positive impact on the overall level of understanding of their perceptions. Table 1 summarizes the main findings in terms of ranking all success factors. The results of the *t*-test are demonstrated in Table 2.

Table 1. Comparison of two groups' means and rank orders

Variable	Mean		S.D.		Rank	
	CZ	DE	CZ	DE	CZ	DE
Strategic character and political support of the whole project	4.21	3.61	0.69	1.01	4	5
Positive country risk classification based on OECD Consensus	3.85	3.58	1.12	1.01	6	6
Exporter's experience with export financing	4.41	4.17	0.49	0.69	2	1
Exporter’s long-lasting track record and stability	4.26	4.00	0.63	1.00	3	2
High credibility of the foreign investor	4.46	3.94	0.59	0.62	1	3
Significant share of technologies and deliveries from domestic suppliers	3.13	3.22	1.24	0.79	7	7
Knowledge of foreign market environment gained through smaller projects	3.92	3.67	1.16	0.75	5	4

CZ, Czech respondents; DE German respondents; Scale: 1 = Strongly disagree, 2 = Disagree, 3 = Partially agree, 4 = Agree, 5 = Strongly agree

Table 2. Results of the *t*-test for two groups (two-tailed)

7 individual items	Degree of freedom	*t*-Value	Two -tail sig. *(P)*	Null hypotheses
Strategic character and political support of the whole project	73	3.00	0.005	Rejected
Positive country risk classification based on OECD Consensus	73	1.06	0.298	Accepted
Exporter's experience with export financing	73	1.78	0.089	Accepted
Exporter’s long-lasting track record and stability	73	1.34	0.199	Accepted
High credibility of the foreign investor	73	3.69	0.001	Rejected
Significant share of technologies and deliveries from domestic suppliers	73	-0.39	0.698	Accepted
Knowledge of foreign market environment gained throu smaller projects	73	1.13	0.263	Accepted

$P<0.05$

4.1. *Perception of key success factors*

The statistical results suggest that the perceptions of Czech and German specialists are very similar in many aspects. The factors No. 3, 4 and 5 were identically ranked among the top three success factors, even though in a different rank-order. In other words, the Czech and German specialists appear to feel strongly that the *exporter’s experience with export financing, the long-lasting track record, stability and high credibility of the foreign investor* are the most crucial success factors. Their standard deviations (SDs) corresponded to the shape of the distribution of variables around the mean values. The final ranking of the remaining four factors shows that there is a general correlation in the ranked order. The Czech similarly as the German experts viewed a *positive country risk classification based on the OECD Consensus* as well as the *significant share of technologies and deliveries from domestic suppliers* as the sixth or seventh most important success factor. In terms of mean values, differences were observed between the mean values of the Czech and German respondents for the two factors: *strategic character and political support of the whole project* (4.21 and 3.61) and *high credibility of the foreign investor* (4.46 and 3.94). The differences in these means were found as statistically significant on the 0.05 level.

4.2. *Strategic character and political support of the whole project*

Political support as well as the involvement of the government on either a local or national level may accelerate the bureaucratic procedures during the project planning phase or the construction itself. A few respondents pointed out that projects with a strategic background are more likely to be granted insurance from ECA. For this factor, the study identified a significant difference in the groups’ perceptions. The Czech practitioners expressed a high level of agreement (mean 4.21), while the German respondents remained more conservative with the overall mean score of 3.61. They frequently stated that strategic character and political support may play a vital role predominantly in public projects in developing countries, while the factor's significance decreases with projects in the private sector.

4.3. *Positive country risk classification based on OECD Consensus*

Regular country evaluations by OECD are directly linked to the country's eligibility for subsidized export credits, including minimal interest rates to be charged. Compared to other examined factors, the country risk classification reached relatively low scoring from both groups (means 3.85 and 3.58 respectively), even sample SDs appeared to be the same. A number of respondents expressed their opinion that risk classification is critical in the initial project phase when stakeholders consider their participation in the project. It was also commented that a positive country rating is associated with trust and a stable economic environment which are the necessary preconditions for a successful completion of every project. Contrary to these statements, it was also stressed that many buyer's credit-based projects were successfully completed even in poorly ranked developing countries.

4.4. *Exporter's experience with export financing*

Exporter's former experience with the export financing scheme was highly evaluated by both groups. It was top ranked by the group of German respondents with the mean score reaching 4.17 points. Interestingly, the Czech respondents granted it even a higher score of 4.41, which is the second most important success factor of project execution under the buyer's credit scheme from their prospective results. According to the result of the *t*-test, the evaluations by both groups do not show any statistical difference. There is clear evidence that exporters' familiarity with the entire financing scheme as well as their understanding of all associated duties and risks lead to project success. ECAs deem former experience with the scheme crucial when considering the credit insurance of large credit volumes associated with extensive projects.

4.5. *Exporter's long-lasting track record and stability*

Exporter's long term stability minimizes the performance risk, which is a frequent cause of project failures, regardless of the way they are financed. Both the Czech and German respondents pointed out that stability and long-lasting track record are deemed as crucial success factors for project completion from the view of the foreign investor, ECA and the financing bank. Very similar mean scores can be observed. This factor was ranked as the second most important success factor by the German respondents and as the third most important factor from the Czech perspective (score 4.00 and 4.26 respectively). The companies without a strong base and sufficient reserves may find themselves in a difficult situation caused by the failure of their single project, which may consequently have a negative impact on their overall stability.

4.6. *High credibility of the foreign investor*

Investor's credibility remains a necessary precondition for the application of the buyer's credit scheme. Some managers pointed out that investor's credibility plays a vital role before the export credit and ECA cover are granted. Others highlighted the necessity of the investor's stable profile during the entire project. Both groups of the respondents expressed a high level of agreement with the statement. With the mean value of 4.46, the Czech managers consider it the most important success factor, whereas the German respondents evaluated foreign investor's credibility as the third most important factor (mean of 3.94). Standard deviations of 0.59 and 0.62 show a very low level of dispersion.

4.7. *Significant share of technologies and deliveries from domestic suppliers*

Every project applying for credit insurance provided by ECA has to fulfill the minimal share of supplies from the exporter's country of origin, which is one of the necessary preconditions set by the OECD Consensus. This factor was poorly ranked by both the Czech and German specialists, earning the score of 3.13 and 3.22. A very low level of agreement was thus expressed with this factor. Low scores were later on explained by the problems which may arise during cross-border supplies in terms of market protection mechanisms. These may account for the necessity of import permissions and additional taxes on imported goods, which may cause additional difficulties and increase the project cost. A significant share of deliveries from the exporter's country of origin remains a necessary precondition in terms of the subsidized ECA cover, but its overall impact on the project delivery remains questionable.

4.8. *Knowledge of the foreign market environment gained through smaller projects*

Smaller pilot projects enable the exporter to get familiar with the conditions and specifics of the selected export market. The factor was ranked in the top fifth or fourth position with means of 3.92 and 3.67. It was frequently commented that the connection to local officials and supply chains significantly facilitated daily operations during the planning and construction phase. Several respondents argued that companies can learn from relevant experience gained through executed pilot projects. It helps to avoid unnecessary pitfalls in the future thanks to valuable lessons learned in the past. Small pilot projects were also strongly recommended for testing new concepts of operation. Small-sized projects also better limit potential losses from activities undertaken in unexplored new territories.

5. Conclusion

The study reveals that in general there is no significant difference between Czech and German export finance practitioners. The factors were prioritized according to their evaluation. This empirical research proved that the success is closely associated with exporter's experience in export financing, exporter's long-lasting track record and stability and high credibility of the foreign investor. These three factors were top ranked by the experts representing the Czech Republic and Germany, the two highly-developed export-oriented economies. Relevant experience and the possession of export know-how thus remains the best qualification for project delivery under the buyer's credit scheme. In order to increase their qualification, construction firms may gain their first experience through project-based joint ventures or via entry into small pilot projects. The findings also imply that both groups have significantly different views on projects' strategic character and their political support as well as high credibility of foreign investors. Despite the findings of this study, the area of success factors in export financing under the buyer's credit scheme still remains a field which deserves further attention and continuing academic research.

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Comparison of ANN and MRA Approaches to Estimate Bid Mark-Up Size in Public Construction Projects

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Abstract

The intense nature of the competition in the construction industry is commonly acknowledged by professionals and researchers. Moreover, the owners commonly select the contractors based on how low they offer their bid prices and outbid their rivals. Gaining competitive advantage in order to win a contract is largely based on considering all cost components very carefully and systematically in estimating the bid price. A typical bid price consists of three main cost components, which include: direct costs (e.g., materials, equipment, labourers, etc.), indirect costs (e.g., salaries of the engineers and technical personnel, security, etc.), and bid mark-up (i.e., general overhead, profit and contingency). In the literature, various tools and techniques have been proposed for estimating bid mark-up size in construction projects. This study compares the prediction performances of the artificial neural network (ANN) and multiple regression analysis techniques (MRA). For this purpose, 52 factors that may affect the size of bid mark-up were identified and actual data of 80 public construction projects were obtained from 27 Turkish contractors in public projects in Turkey. The ANN and MRA based models were developed via MATLAB Neural Net Fitting and SPSS software programs, respectively and their prediction performances were evaluated using several statistical measures.

Keywords: Artificial neural network, bidding, mark-up, multiple regression analysis, public construction projects.

1. Introduction

Contractors predominantly win the contracts through bidding process. Since owners commonly select the contractors based on how low they offer their bid prices and outbid their rivals, contractors should be very careful when they estimate the bid price. If a contractor offers a very low bid price in order to the win the contract in a risky project environment, significant losses may occur. On the other hand, if a contractor offers a very high bid price in order to protect himself from the negative impacts of the potential risks inherent in the project, he may lose the job as the bid price in unnecessarily inflated. Therefore, a bid price should be low enough to win the contract and high enough to cover the potential losses resulted from the risks. In the construction management literature, the components of bid price are defined in several ways. According to one of the most common definition, three main components, which are; direct cost, indirect cost, and bid mark-up, constitute the bid price [1]. Direct costs include the costs of equipment, material, labour, and subcontracting, which are directly involved in the physical construction of permanent facility. On the other hand, indirect costs consist of the costs that are necessary to carry out the production (i.e., field supervision, engineers' salaries, etc.) but do not become a final part of the product. Base estimate is the sum of direct and indirect costs. Base estimate is increased by a bid mark-up, which is an estimated percentage. Bid mark-up involves there components, which are; general overhead cost, contingency, and profit. General overhead cost is the cost required to operate all business activities of a contractor (i.e., rent, utilities, etc.). Profit is the total amount of money that a contractor desires to earn from the construction project in question. Contingency, a.k.a., risk mark-up, is an amount of money allocated for possible unforeseen events that may bring about cost overruns [1-3]. The base estimate of the projects is frequently estimated nearly same by all contractors. Therefore, the bid mark-up size is the key component in bid price, which also determines winning or losing the contract in question. In other words, the right amount of bid mark-up size brings success in competitive bidding

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environment. Since the amount of the bid mark-up size is critical in winning the contract, the size of it should be determined precisely. But determining the right size of bid mark-up size is not very easy task due to the fact that it is affected by several factors, which are highly implicit and intangible [4]. Several techniques [1, 4-12] have been proposed to estimate bid mark-up size in construction projects. However, contractors still lean to estimate bid mark-up size based on their past experience and intuitions, which is highly subjective manner. This study aims to provide two useful bid mark-up size estimation tools for Turkish contractors to predict bid mark-up size in a more realistic, objective and systematic way. To achieve this goal, multiple regression analysis (MRA) and artificial neural network (ANN) methods are selected to develop the estimation models.

2. Research Methodology

The objective of the study is to generate robust estimation models for Turkish contractors that may assist them in determining bid mark-up size using MRA and ANN methods. Therefore, the following tasks were performed in this study. First, the literature was reviewed to identify the factors that may affect the bid mark-up size decision of Turkish contractors' in their bids for public projects. Then, a questionnaire was designed to obtain actual data of 80 public projects based on these identified factors. After this, the general framework of the proposed bid mark-up estimation model was constructed. The MRA and ANN methods were used to generate bid mark-up size estimation models. Finally, the performances of developed models were compared with several statistical indicators.

2.1. *Questionnaire Design*

In the light of the relevant literature [1, 3, 13-17], 52 factors that may affect the bid mark-up size decisions of the contractors were identified. These 52 factors are then categorized into 7 major groups, which are; 1) *Project Characteristics*, 2) *Economic Characteristics*, 3) *Bidding Characteristics*, 4) *Contract Characteristics*, 5) *Owner Characteristics*, 6) *Company Characteristics*, and 7) *Opportunity Characteristics* (see Table 1). In order to develop the general framework of the bid mark-up estimation model, a questionnaire including 73 questions was designed. The questionnaire has two parts. In the first part, the context of the respondent company and the project characteristics were investigated with 16 questions. In the second part, respondents evaluated the magnitudes of 52 factors on a scale consisting of five ratings such as; *very low*, *low*, *medium*, *high* and *very high* for the construction project in question.

Table 1. Factors affecting the bid mark-up size in public construction projects [4].

Major Groups and Their Constituent Factors	
MF_A *Project Characteristics*	
FM_{1A} : Project size	FM_{7A} : Safety problems
FM_{2A} : Project cash flow	FM_{8A} : Project type
FM_{3A} : Project's complexity	FM_{9A} : Need for new techniques and technologies
FM_{4A} : Unfavorable physical conditions of the construction site	FM_{10A} : Vagueness in the project scope
FM_{5A} : Project duration	FM_{11A} : Uncertainties in the cost estimate
FM_{6A} : Design complexities	
MF_B *Economic Characteristics*	
FM_{1B} : Fluctuations in material prices	FM_{3B} : Investment risks
FM_{2B} : High financing costs	
MF_C *Bidding Characteristics*	
FM_{1C} : Vagueness in bidding documents	FM_{4C} : Insufficient time for bid preparation
FM_{2C} : Inexperience of personnel employed in the bidding department	FM_{5C} : Size of required bonds
FM_{3C} : Awarding type	FM_{6C} : Price of the bidding documents
MF_D *Contract Characteristics*	
FM_{1D} : Type of contract	FM_{6D} : Vagueness of contract conditions regarding delays in payment
FM_{2D} : Owner's special requirements, which are not clearly defined in contract documents	FM_{7D} : Unclear contract conditions regarding the rights and responsibilities of the parties
FM_{3D} : Unsatisfactory contract conditions regarding design changes and additional works	FM_{8D} : Vagueness of contract conditions regarding the project time extension
FM_{4D} : Unsatisfactory contract conditions regarding claims due to additional costs arising from the geological conditions of the construction site	FM_{9D} : High taxes
FM_{5D} : Unsatisfactory contract conditions regarding escalations	

MF_E Owner Characteristics	
FM_{1E} : Financial strength of the owner	FM_{3E} : Relationship and past experience with the owner
FM_{2E} : Unsatisfactory contract conditions regarding the dispute resolution method	FM_{4E} : Unreliability of the owner
MF_F Company Characteristics	
FM_{1F} : Current work load	FM_{5F} : Problems regarding time, cost and resource planning
FM_{2F} : Level of experience in similar projects	FM_{6F} : Unavailability of qualified site engineers and managers
FM_{3F} : High turnover of the employees	FM_{7F} : Poor communication and coordination
FM_{4F} : Insufficient number of approved subcontractors	FM_{8F} : Unavailability of necessary equipment
MF_G Opportunity Characteristics	
FM_{1G} : Need for work	FM_{7G} : Potential for gaining future projects from the same owner
FM_{2G} : Number of competitors	FM_{8G} : Competition level in the market
FM_{3G} : Expertise level of competitors	FM_{9G} : Potential for gaining experience in a new construction type
FM_{4G} : Financial weakness of the company	FM_{10G} : Prestige of the project
FM_{5G} : Past bid mark-up sizes in similar projects	FM_{11G} : Project's contribution to the recognition of the company
FM_{6G} : Project's contribution to the growth of the company	

2.2. *General Framework of the Bid Mark-up Size Estimation Model*

MRA and ANN methods are used to estimate the bid mark-up size in the public projects. The bid mark-up size estimation model has seven inputs (i.e., MF_A: Project Characteristics, MF_B: Economic Characteristics, MF_C: Bidding Characteristics, MF_D: Contract Characteristics, MF_E: Owner Characteristics, MF_F: Company Characteristics, and MF_G: Opportunity Characteristics) and one output (i.e., *BM*: Bid Mark-up size). The magnitudes of the 7 major factor groups (MF_i) are used to model the function of the bid-mark-up size (*BM*). The following equation is used to express the relationship between *BM* and MF_i for each major risk group:

$$BM = f(MF_A, MF_B, MF_C, MF_D, MF_E, MF_F, MF_G) \tag{1}$$

where *BM* represent the bid mark-up as a percentage of total contract value, and MF_i represent the magnitude of each major risk group *i*, respectively. The magnitude of each major risk groups is determined as the average of the magnitudes of constituent risk factors (FM_{ji}) in each major risk group.

2.3. *Multiple Regression Analysis (MRA)*

A regression analysis is basically used to find analytical form of relation between one dependent variable and one or more independent variables [18]. Simple and multiple regression analyses (MRA) are two types of linear regression. Simple regression is used to explain variance of a dependent variable with only one independent variable. On the other hand, MRA is used when there is more than one independent variable to explain a proportion of the variance in a dependent variable at a significance level. The general form of multiple regression equation is given below (Eq. 2):

$$Y = b_0 + b_1 \times X_1 + b_2 \times X_2 + \ldots + b_n \times X_n + \varepsilon_i \tag{2}$$

where *Y* is a dependent variable (*i.e., output or criterion variable*); b_o is the constant of the regression equation; and b_1-b_n are the regression coefficients; X_1,...,X_n are independent variables (*i.e., inputs, predictor variables, explanatory variables*); and ε_i is a random error.

2.4. *Artificial Neural Network (ANN)*

ANN is a kind of computational method, which is basically inspired from the human brain. It mimics the cognitive power of human brain with artificial neurons and network to solve complex problems [19]. The nodes are the highly interconnected computational units of the system, and their role is to receive inputs and transform into output by processing them [20]. Typical ANN is composed of three layers namely, input, hidden, and output layer. The feed-forward and feed-back are two major types of architecture exist in ANN based on the connection patterns [21]. The learning mechanism of ANN depends on the architecture of the system. The learning ability of ANN provides updating the network architecture and weight of connections to work efficiently for performing special tasks. The learning algorithm is a procedure, which employs the learning rules to adjust weights during updating process. Learning from past examples is the superiority of the ANN, which also makes it desirable than the other methods [22].

3. Findings and Discussion

3.1. *Sample Characteristics*

The designed questionnaire was sent to 43 Turkish contractors, who predominantly undertake public construction projects. Only 27 respondent contractors fully completed the delivered questionnaire. Out of the 27 contractors, 8 of them have more than 40 years of experience in the construction industry and 24 of them employed more than 100 workers. The distribution of the 80 construction projects according to their types were as follows; 48.15% of them institutional and commercial building construction, 25.93% of them residential housing, 14.81 % of them heavy construction, 3.70% of them industrial construction, and 7.41% of them were other type. The contract values in the studied projects ranged between less than 50 million TL (i.e., 45.24%) to more than 250 million TL (i.e., 14.29%). In the studied projects, 78.75% of the respondents were prime contractors, 19.05% of them joint were venture member, and 2.38% of them were subcontractors. Also, only 2.38% of the contractors used basic statistical methods to estimate bid mark-up size, and the rest of them did not use any estimation methods. On the other hand, the actual bid mark-up size of the studied projects mostly ranged between 11% and 15% of the contract value.

3.2. *Development of Multiple Regression Analysis Model*

The developed multiple regression analysis model (MRAM) has six independent variables (i.e., MF_A, MF_B, MF_C, MF_D, MF_E, MF_F, and MF_G) and one dependent variable (i.e., BM). Before applying regression analysis, the correlation between inputs and output was examined and it was observed that the independent variables were highly correlated with dependent variable. After checking correlation, the multiple regression analysis was conducted via statistical package SPSS 22 in order to obtain the relationship between dependent variable and independent variables. The significance level is specified as 0.05 ($\alpha = 0.05$) for this study. The multiple regression equation was obtained based on the actual data of 80 public projects (Eq. 3). The unstandardized coefficients of parameters of regression equation and their significance level calculated and it was observed that all parameters of the model were significant at the confidence level of 95%.

$$\begin{aligned} BM = {} & 8.840 + 0.598 \times MR_A + 0.107 \times MR_B + 0.603 \times MR_C + 0.520 \times MR_D + 0.516 \times MR_E \\ & + 0.653 \times MR_F - 0.856 \times MR_G \end{aligned} \tag{3}$$

3.3. *Development of Artificial Neural Network Model*

The Neural Net Fitting application of the MATLAB was utilized to generate the bid mark-up size estimation model. The setting parameters of the artificial neural network model (ANN) were as follows: the feed-forward backpropagation network was utilized as the type of architecture; the training function was selected as Levenberg-Marquardt method; gradient-descent-with-momentum adaptation was used as the learning function of the network; the performance evaluation was determined with mean squared error (MSE) function, and tangent sigmoid (TANSIG) transfer function were selected as the activation function of the bid mark-up size estimation model. Actual data of 80 public projects were divided into three parts; 70% of them (56 projects) were used in training process, 20% of them (16 projects) were used in cross validation process, and the rest 10% of them (8 projects) were used in the testing process of the network. The number of training iteration was 1000 epochs. In order to find the best ANN model, a trial and error method based on the variation of the number of neurons in the hidden layer was performed. For that purpose, the performance of the generated models were evaluated with using several statistical indicators, which are the mean absolute percentage error (MAPE), root mean square error (RMSE), correlation coefficient (R), and coefficient of determination (R^2). Table 2 presents the performances of generated models.

Table 2. Performance indicators of ANN bid mark-up size estimation models.

	Developed models								
Performance Indicator	ANN_2	ANN_3	ANN_4	ANN_5	ANN_6	ANN_7	ANN_8	ANN_9	ANN_{10}
Number of neurons	2	3	4	5	6	7	8	9	10
MAPE (%)	2.9865	2.8231	2.7066	2.4023	6.4285	6.4012	5.0480	4.8822	4.9566
RMSE	0.4648	0.4263	0.4444	0.4583	1.1597	0.8673	0.9360	0.6925	0.8627
R	0.992	0.993	0.992	0.992	0.949	0.972	0.973	0.986	0.971
R^2	0.985	0.986	0.985	0.984	0.900	0.945	0.947	0.972	0.944

The ideal model is identified with minimum MAPE and RMSE, and maximum R and R^2, which means that MAPE and RMSE values should be close to zero, on the other side, R and R^2 values should be close to one. Based on the findings presented in Table 2, the most satisfactory model was the ANN_3, which consists of 3 neurons in the hidden layer. Therefore, ANN_3 is selected for representing artificial neural network model of this study.

3.4. *Comparison of MRA and ANN Bid Mark-up Estimation Models*

The performances of the developed models were evaluated by comparing actual bid mark-up size of 80 public construction projects with the predictions of the estimation models. Table 3 presents the actual values of the major risk groups and bid mark-up size obtained from 80 projects, and the mark-up sizes predicted by the developed MRA and ANN models. Because of the page limitations, all values of the 80 projects could not be shared in Table 3.

Table 3. Actual data for 80 public construction projects and the predictions by four multiple regression analysis models.

Project No.	Magnitude of Major Risk Groups*							Actual Bid Mark-up Size (BM) (%)	Predicted Bid Mark-up Size (BM) (%)	
	MF_A	MF_B	MF_C	MF_D	MF_E	MF_F	MF_G		MRAM	ANN_3
1	4.55	4.33	4.33	3.78	3.25	3.25	1.27	18.00	18.14	18.24
2	3.00	2.00	2.83	1.67	1.00	1.25	3.82	11.00	11.13	11.05
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
79	3.18	2.33	3.00	2.00	1.50	1.38	3.27	11.00	12.18	12.12
80	3.00	2.33	2.83	1.78	1.50	1.38	3.64	12.00	11.54	11.42

* Scale 1-5: 1= very low, 2=low, 3= medium, 4= high and 5= very high.

The performances of the proposed bid mark-up estimation models (i.e., MRAM and ANN_3) were evaluated by using the mean absolute percentage error (MAPE), root mean square error (RMSE), correlation coefficient (R), and coefficient of determination (R^2) (see Table 4).

Table 4. Performance indicators of MRA and ANN bid mark-up estimation models

Performance Indicator	Developed Models	
	MRAM	ANN_3
MAPE (%)	2.7337	2.8231
RMSE	0.4115	0.4263
R	0.993	0.993
R^2	0.987	0.986

Findings indicate that there was only slight difference between the performance of MRAM and ANN_3 bid mark-up estimation models. The MRAM has lower MAPE and RMSE and slightly higher R^2 than the ANN_3. These findings revealed that predictions of both MRAM and ANN_3 are satisfactory. Therefore, Turkish contractors can use these robust estimation models in order to predict the bid mark-up size in a more realistic, objective and systematic way for providing competitive advantage against to their rivals.

4. Conclusion

The aim of this study is to show how MRA and ANN methods can be used as a bid mark-up size estimation tool by contractors in order to make realistic predictions in a more systematic way. Therefore, two robust bid mark-up size estimation models were developed based on the data obtained form 80 public construction project that had been completed by 27 Turkish contractors. Statistical indicators were used to compare performances of the developed models. It was found that both models were satisfactory in estimating bid mark-up size. Future studies should focus on extending the proposed models via collecting more data to construct more generalized and accurate bid mark-up size estimation model.

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Smart Home Subcontractor Selection Using the Integration of AHP and Evidential Reasoning Approaches

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Abstract

Subcontracting is a very common practice in the construction industry. The large portions of actual production work are carried out by subcontractors. Therefore, main contractors have focused on selection of the appropriate subcontractors to increase the performance of their business. Finding the most suitable alternative among these subcontractors is another complex task because assimilating a large number of aspects is not simple without using any selection tools. In order to understand this better, breaking down the problem into smaller parts and building a model is one of the best ways in the selection process. Companies want to make differences to increase buyers’ interest; this is to obtain better position in the competitive construction market. Recently, the popularity of smart home and home automation has importantly increased in modern societies in Turkey. This has lead construction companies to import the smart home system into their business investments. This study aims to propose an integrated model for selection of smart home subcontractor. The proposed model integrates Analytic Hierarchy Process (AHP) and Evidential Reasoning (ER) techniques. In this study, AHP is used to find the weights of the criteria that are considered in the smart home subcontractor evaluation process and ER is employed to rank the alternative subcontractors. The proposed approach is applied in a construction company that has completed many projects in Turkey. In the case study, twenty evaluation criteria are considered and eight alternative smart home companies are evaluated. The result of this study demonstrated that the suggested model is applicable.

Keywords: Analytic hierarchy process; case study; evidential reasoning; smart home; subcontractor selection

1. Introduction

A subcontractor can be defined as an individual or a company hired by a main contractor to carry out specific tasks on a construction project and/or supply resources (e.g., laborers, materials, equipment, tools) and designs [1-2]. Subcontracting has become a very common practice, as the main contractors’ have been much more willing to sublet a large portion of their work for various reasons (e.g., financial benefits, resource constraints, better efficiency) [3]. According to Hinze and Tracey (1994) [4], indeed, subcontractors are hired to perform 80-90% of the tasks on many construction projects, especially building projects. It should be noted that even though subcontracting is a very common practice, it is also a very risky practice. Having a group of unknown subcontractors which are hired to carry out the majority of the tasks in a project can be a disadvantage in some circumstances. The main contractor may fail to coordinate subcontractors or control the quality and progress of their works [3, 5-9].

Since the main contractor takes prime responsibility for the performance of the subcontractors, the selection of the most appropriate subcontractor is crucial to complete the project successfully in terms of time, cost, and quality [10-14]. Nevertheless, many contracting companies underestimate the risk of not being able to complete the project successfully due to selecting their subcontractors solely based on the lowest bid. This type of selection increases the possibility of selecting unqualified, incompetent, inexperienced, and insufficiently financed subcontractors [11-13, 15-16]. Besides, the consequences of hiring inadequate subcontractors may be severe, such as claims, disputes, litigations, adversarial working conditions, penalties, abandonment of work, bankruptcy. Therefore,

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considering several factors in selection of subcontractors is important for the success of construction companies, rather than only taking bid prices into account when they select their subcontractors.

The selection of smart home subcontractors gained more importance, as the popularity of smart home and home automation has increased in Turkey. The main objective of this study is to propose an approach to provide contracting companies with a tool that will support them overcome the challenge of selecting the most appropriate subcontractor for their projects. In the proposed approach, two multi-criteria-decision-making methods namely, Analytic Hierarchy Process (AHP) and Evidential Reasoning (ER), were integrated. The proposed approach is also applied in a construction company, which is the main contractor of a residential project that consists of smart home systems.

2. Research Methodology

A review of literature shows that there are several studies focused on developing a model for subcontractor selection. However, studies that are focused on selection of smart home subcontractor are very limited. The aim of this study is to propose an integrated approach for selection of smart home subcontractor. For this purpose, the following tasks were performed: (1) determining the factors that have an impact on selection of smart home subcontractor; (2) integrating AHP and ER methods for selection of smart home subcontractor; and (3) applying the integrated approach to solve a smart home subcontractor selection problem of a Turkish construction company. The following sections provide information about AHP and ER methods.

2.1. *The AHP method*

Even though there are various methods to solve multi-criteria-decision-making problems, AHP has become one of the most commonly used methods after it was developed by Thomas Saaty [17]. The main steps of AHP method are as follows: (1) defining the decision problem and determining its goal, (2) development of the decision hierarchy, (3) establishment of the pairwise comparison matrix, (4) calculation of the weights of the criteria, and (5) calculation of the consistency ratio [18-19].

Defining the decision problem and determining its goal is the first step of AHP method, as it is the same for many methods that are used to solve multi-criteria-decision-making-problems. The second step, development of the decision hierarchy, involves the identification of the problem goal, selection of criteria and possible alternatives. If a decision-maker needs to represent the decision hierarchy in details, then he/she can add several levels (i.e., main criteria, sub-criteria, etc.) to the decision hierarchy. In the third step, pairwise comparison matrix is established after developing the decision hierarchy. The comparison of the importance of the selection criteria is done in pairs according to the goal of the decision problem using the nine-point rating scale which is represented in Table 1 [17]. In case of having more than one decision maker, the judgments of the decision-makers in the pairwise comparison matrices should be aggregated using the geometric mean. The next step comprises the calculations of the weights of the criteria. First, each element in the pairwise comparison matrix is divided to the sum of its own column. Then, the arithmetic mean of each row is calculated to obtain the weights of the criteria. In order to measure the consistency of the decision maker's judgements, the Consistency Ratio (CR) in each pairwise comparison matrix calculated in the final step of the AHP method. Any value less than 0.1 indicates that the judgements of the decision maker(s) are consistent. If CR is greater than 0.1, the pairwise comparisons should be repeated by the decision maker(s) until obtaining a value of CR that will be acceptable.

2.2. *The ER method*

Lowrence et al. (1986) developed ER method to solve multi-criteria-decision-making problems by using the evidence and decision theory of Dempster-Schafer [20]. One of the most important advantages of ER method is that it allows to use of both quantitative and qualitative data. In order to model the uncertainties inherent in information related to a problem, belief structure and belief decision matrix are employed in ER method [20-21]. ER method mainly consists of three steps namely, (1) development of the hierarchy, (2) data transformation, and (3) evaluation of alternatives. In the first step, the problem hierarchy is developed by defining the assessment criteria and alternatives. Subsequently, the criteria weight and utility are used to define a belief decision matrix. ER method allow the decision-maker to use different types of data (precise numbers, interval numbers, belief structures, etc.) to evaluate the alternatives according to the assessment criteria. The second step involves the transformation of different types of evaluation data to a common framework in order to make comparison and aggregation. This transformation is done by using rule or utility based information transformation techniques. The final step is based on the aggregation of all type of information thorough the ER algorithm. The weights of the assessment criteria and the evaluations of alternatives according to the criteria are used to rank the alternatives.

3. A numerical application of the proposed approach

A real-life case study is provided where the steps of the proposed approach are used for subcontractor selection. The content of the case study is based on a subcontractor selection of a Turkish construction company. The company is the main contractor of a residential project that consists of smart home systems. The construction company is interested in finding subcontractors, which are specialized in installation of smart home systems. The decision-making team of consists of four experienced engineers, who are assigned to manage the subcontractor selection process. First of all, team members determined the criteria that should be taken into account during the selection of the subcontractor in the case study. They determined eight main criteria namely, “quality of service” (MC-1), “level of experience in different building types” (MC-2), “financial capacity” (MC-3), “cost” (MC-4), “technical capability” (MC-5), “past experience with the company” (MC-6), “quality of the product” (MC-7), and “experience in implementation technique” (MC-8). Five of these main criteria have sub-criteria which are quality of call center service (SC1-1), “qualifications of the employees” (SC1-2), “duration of providing service” (SC1-3), “duration of providing spare parts” (SC1-4), “experience in single house” (SC2-1), “experience in apartments” (SC2-2), “experience in hotels” (SC2-3), “capital cost” (SC4-1), “operational cost” (SC4-2), “maintenance cost” (SC4-3), “capability of the R&D department” (SC5-1), “production technology” (SC5-2), “capability of pursuing new technologies” (SC5-3), “qualifications of the technical personnel” (SC5-4), “wireless” (SC8-1), “wired” (SC8-2), “mixed” (SC8-3). After determining the criteria for selection of smart home subcontractor, the decision-making team formed the decision hierarchy (Figure 1) as a first step of the AHP method, which is used to compute the relative priorities of the criteria.

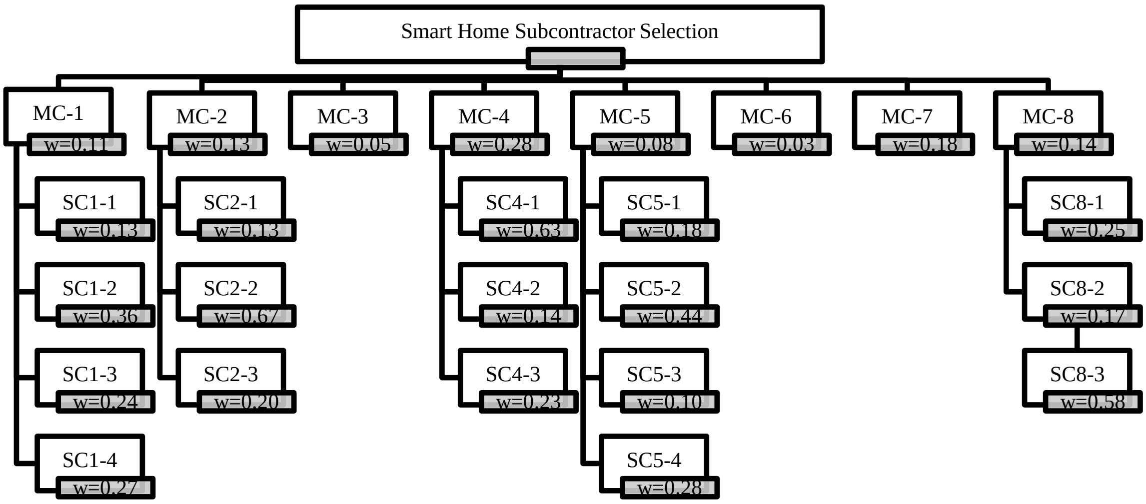

Figure 1. Decision hierarchy of smart home subcontractor selection problem

The decision makers compared the subcontractor selection criteria in pairs using the Saaty’s (1980) [17] rating scale. Subsequently, they evaluated the alternative subcontractors according to each criteria using the nine-point scale (Table 2).

Table 1. 9 Point scale used for smart home subcontractor evaluation

Linguistic Variable	Numerical value
Very Bad (VB)	1
Very Bad-Bad (VB-B)	2
Bad (B)	3
Bad-Average (B-A)	4
Average (A)	5
Average-Good (A-G)	6
Good (G)	7
Good-Very Good (G-VG)	8
Very Good (VG)	9

Since there were four engineers in the decision-making team, group decision making techniques were used in the AHP calculations. The decision making team individually formed the pairwise comparison matrices and calculated the geometric values of these values to get the final pairwise comparison matrix. Only the aggregated pairwise comparison matrix is presented in Table 2 rather than presenting the aggregated pairwise comparison matrices established for the sub-criteria due to the space limitations.

Table 2. Pairwise Comparison Matrix for 8 Main Criteria and Results Obtained from AHP Computations

Criteria	MC-1	MC-2	MC-3	MC-4	MC-5	MC-6	MC-7	MC-8	Weights	
MC-1	1.00	0.67	2.22	0.37	1.73	5.32	0.55	0.95	0.11	
MC-2	1.50	1.00	2.06	0.32	1.93	5.54	0.74	0.76	0.13	
MC-3	0.45	0.49	1.00	0.28	0.53	2.00	0.24	0.25	0.05	
MC-4	2.69	3.08	3.57	1.00	4.12	7.42	1.78	2.00	0.28	
MC-5	0.58	0.52	1.88	0.24	1.00	3.46	0.45	0.71	0.08	
MC-6	0.19	0.18	0.50	0.13	0.29	1.00	0.17	0.21	0.03	
MC-7	1.81	1.35	4.24	0.56	2.24	6.05	1.00	1.57	0.18	
MC-8	1.06	1.32	3.94	0.50	1.41	4.70	0.64	1.00	0.14	CR: 0.01

According to the results presented in Table 2, "cost" (MC-4), "quality of the product" (MC-7), and "experience in implementation technique" (MC-8) have the highest weights, respectively. On the other hand, "past experience with the company" (MC-6), "financial capacity" (MC-3), and "technical capability" (MC-5) have low impact on the selection of smart home subcontractor. Consistency ratio (CR) of the pairwise comparison matrix is calculated as $0.01 < 0.10$, which indicates that the judgment matrix is consistent and the weights can be used in the selection process.

Even though four engineers were involved in formation of the aggregated pairwise comparison matrix, only the team supervisor evaluated the alternative subcontractors according to the assessment criteria using the nine-point evaluation scale shown in Table 1. Evaluation results of the decision maker are shown in Table 3.

Table 3. Evaluation matrix of subcontractors

Criteria	Unit	Best Value	Weight	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
MC-1			0.11								
SC1-1	-	Max	0.13	G	B-A	A	B	A	VB-B	A-G	B
SC1-2	-	Max	0.36	G-VG	A-G	A	B	G	B	A	B-A
SC1-3	Day	Min	0.24	7	1	3	3	7	1	7	3
SC1-4	Day	Min	0.27	30	3	7	30	30	7	30	7
MC-2			0.13								
SC2-1	-	Max	0.13	B	G-VG	A	B-A	B	B	B	B
SC2-2	-	Max	0.67	G	A	A-G	VB-B	A	VB-B	B-A	B
SC2-3	-	Max	0.20	G-VG	A	A	VB	A-G	VB	A	B-A
MC-3	-	Max	0.05	G-VG	A	A-G	B-A	G	B	G	A
MC-4			0.28								
SC4-1	Euro	Min	0.63	800	700	760	1100	1300	650	1400	690
SC4-2	Euro	Min	0.14	1050	540	900	460	1500	600	1200	1100
SC4-3	Euro	Min	0.23	250	50	300	250	250	50	200	250
MC-5			0.08								
SC5-1	-	Max	0.18	G-VG	A-G	A	B-A	B-A	VB-B	A-G	B
SC5-2	-	Max	0.44	G	A-G	A	A-G	A-G	B-A	G	A
SC5-3	-	Max	0.10	A	G	B-A	A-G	A	B-A	A-G	B-A
SC5-4	-	Max	0.28	G-VG	A-G	A	VB-B	A	VB-B	A-G	A
MC-6	-	Max	0.03	A	VG	G-VG	A-G	B	A-G	B	G
MC-7	-	Max	0.18	G-VG	A-G	A	A	G-VG	B-A	G	A
MC-8			0.14								
SC8-1	-	Max	0.25	B	G-VG	B	A-G	VB-B	VB	B	VB-B
SC8-2	-	Max	0.17	G	A-G	A-G	VB	A	B-A	A-G	A
SC8-3	-	Max	0.58	B-A	G	B	VB	B	VB-B	A	B

When the AHP computations are over, ranking of the alternative subcontractors was done via IDS-Intelligent Decision System for Multiple Criteria Assessment software program, which is specifically developed for ER computations. When the required data regarding the weights of the criteria, evaluations of alternatives according to assessment criteria are inputted, IDS performed all the required computations to obtain the ranking of alternative subcontractors. Ranking results of the alternatives are shown in Table 4. According to the ranking results, the subcontractor referred as A2 is suggested as the best alternative, which was followed by subcontractor A1, A3, and A8, respectively.

Table 4. Alternative rankings

Alternative	Assessment Score	Ranking
A1	0.6800	2
A2	0.7523	1
A3	0.5762	3
A4	0.3430	8
A5	0.4032	6
A6	0.5071	5
A7	0.3914	7
A8	0.5290	4

The results of the case study validated the usefulness of the proposed approach by providing the same decision that was made by the contractor's team that is in charge of selecting subcontractors. Indeed, the supervisor of the decision-making team stated that subcontractor A2 was selected to install the smart home systems on the residential project, which the construction company has agreed to perform. The opinions of four decision makers, who had the opportunity to use the proposed model, were sought through face-to-face interviews in order to check the validity of the developed model and its usability in their company. The decision makers stated that the developed DEA model was a useful and efficient tool, and could be easily used in their company for subcontractor selection in future projects.

4. Conclusion

Selecting the appropriate subcontractor is one of the most important factors that affect the success of a contracting company. In this study, an approach that integrates the AHP and ER methods was proposed to provide construction companies with a tool that can be used in selection of the most appropriate subcontractor. The proposed approach was applied to a smart home subcontractor selection problem of a construction company, which is the main contractor of a residential project in Istanbul, Turkey. According to the results of this study, the subcontractor referred as A2 is suggested as the best alternative, while the subcontractor A4 was found to be the worst among eight alternatives. The results also validated the usefulness of the proposed approach as it provided the same alternative that was selected by the contractor's team that is in charge of selecting subcontractors.

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Innovation Management System for Construction Companies

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Abstract

A number of innovation management systems have proven to be successful to companies in several industries from automotive to software development. These systems include for example innovation portfolio management process (Cooper, 1990) and open innovation (Chesbrough, 2004). However, these innovation management systems are not widely adapted in the construction sector. In fact, companies in the sector seem to lack a structured innovation management system. This study aims to develop an innovation management system for construction sector companies that can be applied in practice.
The study was conducted by developing and testing an innovation management system in real-life innovation projects with the top management of major publicly listed Finnish construction companies during 2012-2014. The innovation management system has four key functions, which are Strategy, Market input, Development process and Competencies and resources. Also, the results are analyzed to identify what innovation management system features gave most value for the case companies.
The main finding of this study is that construction sector companies can utilize and benefit from innovation management systems found in literature. Interestingly, the analysis of the innovation projects' results highlighted that especially the market input function added significant value to the existing innovation processes of the companies. The function complemented existing innovation processes of the companies as it was the function that was missing or that was not systematically implemented. The market input function helps to steer the development process and facilitate fact-based innovation investment decision-making. The function consists of four elements, which are Customer needs, Regulation, Technology, and Competitors. After the completion of the present study, the market input function has been widely adapted in the Finnish construction sector and applied in more than 120 major industry projects.

Keywords: construction; decision-making systems; innovation; knowledge management; risk analysis

1. Introduction and research question

Innovation management is a widely researched topic in the academic literature covering both management and leadership issues. A number of managerial systems for innovation management are widely adapted and proved to be successful to companies in several industries from automotive to software. The necessity of having a systematic approach to managing innovation is summarized well by Lewis Lehr, the former CEO of 3M: "Innovation can be a disorderly process, but it needs to be carried out in an orderly way" [1]. However, these managerial systems are not widely adapted in the construction sector. The rate of innovation in construction sector lags behind most other sectors. A systematic approach is needed to manage both the development of innovation and adoption of innovation in construction projects. [2, 3, 4, 5, 6].
In practice, there is an urgent need to understand how innovation is currently managed in the construction sector and to develop means to speed up the innovation process. For example, as the requirements related to a building's design and performance increase constantly, investigation of client needs and utilization of client feedback in management, design and development of new services and products are essential for construction innovation [7]. In particular, there is a practical need for a construction innovation management system tailored to company top management.

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Hence the research question of this paper is formulated as follows:

"How construction companies can utilize innovation management systems?"

In order to answer the research question, this paper aims to develop a system for construction company innovation management. The research methodology in this study is inspired by constructive research approach (CRA), which was originally introduced by Kasanen, Lukka and Siitonen [8]. CRA was selected because it emphasizes the practical applicability of the research results [8]. The present study is carried out in 3 research phases. First, literature is reviewed to develop a theoretical framework for the innovation management system. Second, the theoretical framework is developed further based on feedback from construction company top management and results from 10 innovation projects implemented with four major construction sector companies. Finally, the results from the innovation projects are reported and the functions of innovation management system are described.

The contribution of the paper is in the development of a system for construction company innovation management and analysis of the innovation project results. By developing the system this study increases understanding of how construction companies can manage innovation and how they can increase the efficiency of their innovation systems.

In this study, construction sector comprises the functions of construction project management, on-site production activities or manufacturing and distribution of construction products and components. Construction company is defined as a company that performs one or more of these functions. Innovation on the other hand is defined as creating new products and services, which can mean both new technology and new ways of marketing and selling existing products.

2. Literature overview and formulating the framework for innovation management system

This section introduces the literature streams that have motivated this research and the key concepts that have been utilized in this research. Finally, based on literature overview a theoretical framework for the innovation management system is formulated to be tested in practice.

2.1. *Construction innovation characteristics*

Innovation in the construction sector has been studied for several decades. While the subject has been studied both from single company's point of view and from the industry's point of view, the emphasis has been on the latter perspective. Construction sector has several characteristics, which have an effect on innovation management. Value chains in the sector are usually long and complex by nature, activities are project based, the regulatory influence on the sector is substantial and the industry is often considered to be conservative [2, 9]. The role of regulations as a driver and barrier of construction innovation has been emphasized particularly in sustainability innovation studies [10, 11, 12].

Several studies have pointed out that these characteristics pose challenges to construction innovation [2, 3, 4]. Kajander et al [5] found that modern innovation processes that involve customers and value network are not widely adapted among construction companies. Sivunen et al [13] found that some of the key challenges for construction companies appear to be team building, high R&D-intensity and commercialization management. The innovation process in the construction sector can be cost-intensive with very indefinite returns and companies might lack the proper tools to manage the innovation process [12, 14]. In addition, construction innovations tend to be incremental instead of aiming to create new business [6].

Based on the reviewed literature, it is evident that construction sector has numerous challenges for innovation management, and that these challenges are relatively thoroughly studied in earlier literature. However, only a few studies have tried to look at the problems form a single company's point of view. In effect, there is a lack of innovation management system for construction companies that addresses the problems from a company level.

2.2. *Theories behind the innovation management system*

In the following, selected innovation management systems for construction company innovation management challenges are briefly reviewed. The aim is to identify the theories and innovation systems to develop the framework for construction innovation management system.

Cooper [15, 16] has studied extensively how to manage product development processes. Cooper [15] introduced a systematic way called the Stage-gate model to manage innovation process inside an organization. In the Stage-gate system the R&D process starts from a set of R&D ideas and is divided into a predetermined set of five stages: 1) preliminary assessment of potential R&D ideas, 2) detailed investigation of the selected idea, 3) development,

4) testing and validation, 5) full production and market launch. The system does not describe the generation of product ideas, except that they are invented in-house [15]. Cooper et al [16] have also studied how companies should manage their product development process as a portfolio. When managing a portfolio of R&D projects, the company has four goals: maximizing the value of the portfolio, creating a balanced portfolio, building strategy into the portfolio and choosing the right number of projects. The decision of selecting projects can be made with help from financial methods, strategic approaches, scoring models etc. [16].

The product development innovation systems have mainly focused on closed R&D that is conducted inside an organization, which has been very successful in the past yielding excellent results that have been feeding even more innovation and profits [17]. In the last couple decades, the closed innovation paradigm has begun to shift towards a paradigm of open innovation. In the era of high mobility of workers and private capital available for investments, the open innovation seems to be more natural way to produce innovations. Open innovation essentially means that firms can and should use both internal and external resources in idea generation and idea commercialization [18]. A company can acquire necessary technology through IP or company acquisitions and can sell IP of designs that are not useful for the company's business model as well as doing all this in-house. Also spin-off companies originated from company's R&D activity are common. Spillovers created by R&D can thus be utilized and seen as an advantage rather than a cost of doing business [18].

The Service-Dominant logic innovation theory [19, 20, 21, 22] has been developed to explain discontinuous innovation processes by removing the distinction between product and service innovation. The S-D logic focuses on customer's role and provides a customer-centric view to analyzing, managing, and developing innovation processes. According to the S-D logic, innovation development should always be strategically targeted at a specific customer need [19].

Innovation leadership and corporate innovation governance has been widely researched by Jean-Philippe Deschamps. Deschamps [23] claims that because of the complexity nature of innovation different types of leaders seem to be needed at different stages of the innovation process. For example, innovation activities, and thus leadership imperatives, are quite different at the ''fuzzy front-end'' and ''speedy back-end'' of the innovation process. The front-end of innovation depends upon sensing new market needs, exploring new technologies and generating new ideas in support of the business strategy. It also involves seeding and developing new concepts for products and services, as well as nurturing new ventures through their early stages. The back-end of innovation, by contrast, depends on getting to the market fast in order to reap the rewards. It deals with concrete but critical tasks such as developing, testing, engineering, producing and launching new products or services. [23].

However, it is not obvious what kind of innovation systems different organization should adopt. Hansen and Birkinshaw [24] have created a system called "innovation value chain" for companies to find the best way for them to manage the innovation process. They provide tools for utilization of both internal and external resources in the innovation process. The innovation value chain provides concrete measurements for selecting the innovation systems that are appropriate for each company. Each case is different and companies thus need to figure out which systems make the most sense for them to adopt. This system helps the company to find the weak spots of the innovation process instead of focusing on the good sides to excess.

2.3. *Formulating the framework for innovation management system based on the literature overview*

Groundwork for the framework was laid in the process of studying innovation systems and challenges found in the literature overview. Based on review of the chosen innovation systems and challenges, main functions for the framework were constructed. Table 1 presents the framework for the innovation management system.

Table 1, Framework for the innovation management system

Innovation challenges in the construction sector	Related innovation management systems	Corresponding main function of the framework
Scattered value chain [2]	Open innovation [17], SD-logic [19]	Market input, competences and resources
Project based nature [2]	Innovation leaders and strategy [23]	Strategy, development process
Incremental innovation [6]	Innovation leadership and strategy [23], innovation portfolio management [16]	Development process
High R&D intensity [13]	Open innovation [17]	Competences and resources
Lack of proper tools [5]	Innovation portfolio management and stage-gate tool [15, 16], innovation value chain [24]	Development process
No driving organization for innovation [2]	SD-Logic [19], innovation leadership [23]	Development process

3. Development of the innovation management system

Further development and practical testing of the innovation management system was carried out between 2012 and 2014 together with four major Finnish construction sector companies. 10 real-life innovation projects were implemented. Companies involved in the projects have an annual revenue of over 10 billion euros and companies have significant operations throughout Europe in addition to operations in Finland. Companies include both contractors and construction product manufacturers. The case companies were already implementing various innovation activities before the projects. Main goal of the projects was to test whether the functions presented in the theoretical framework were relevant for the companies and to deepen the content of the framework with sub-functions that would be observed during the projects. Furthermore, an important goal of the projects was to solve problems related to the companies' innovation management process.

Before the actual innovation projects were implemented, the framework for innovation management system was analyzed with the top management of the companies. First, a workshop was held where each company's specific innovation management related problems were pinpointed. Second, interviews with the company representatives were carried out during some of the projects. Third, the collected data was analyzed. Data collected in the workshops and interviews were sources of information for further developing the framework. Sub functions were added to the framework based on the analyses. Finally, the developed sub-functions as well as main functions of the innovation management system were assessed by the authors and company top management. The aim was to analyze whether the functions and sub functions of the framework were relevant for the companies. Based on the results of the workshops and interviews, following sub-functions presented in Figure 1 were added to the framework.

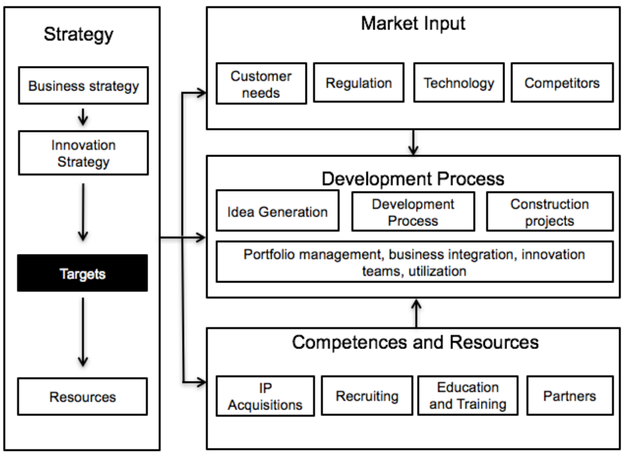

Figure 1. Innovation management system for construction companies

In the next phase, companies tested the innovation management system in innovation projects. Now the emphasis was on solving particular innovation related problems of the companies. Companies 3 and 4 were willing to test the whole innovation management system. Company 1 was interested in testing market input, competences and resources and development process –functions. Company 2 was willing to test the market input –function.

Strategy function was tested by companies 3 and 4. Result of the projects was an analysis of the companies' innovation strategy. Current innovation strategies were analyzed and main problems related to the implementation of the strategy were identified. Based on the problems identified, the best practices of innovation management were analyzed from several leading companies and a revised innovation strategy was formulated. Companies 1 and 2 were already implementing the strategy function at a level that projects addressing the function were not perceived to add significant value for the companies.

Market input function was tested by all companies. The projects related to market input function were for example analyses of target customer needs and feedback, projects of competitor companies and technological development. Also most potential production technologies to be adapted by the companies, for example on-site robotics, were analyzed. All of the projects related to market input function addressed customer needs, technology and competitors and project results were used in the innovation investment decision-making of the companies. A key problem for all companies was how to make fact-based innovation investment decisions in a very short timeframe with limited and ambiguous data. Regulation –sub function was tested with company 3 by analyzing potential changes in relevant regulatory topics.

Competences and resources function was tested with companies 1, 3 and 4. The projects were related for example to analyzing intellectual property of competitor companies by studying new patent filings and product launches. Also idea generation was implemented in the spirit of open innovation by analyzing competitors' new products and technologies. Company 2 assessed that further testing the function would not provide significant value for the company.

Development process function was tested with companies 1, 3 and 4. Emphasis was on the analysis of companies' innovation management processes. Problems and challenges related to the development process were identified and solved based on the theories included in the framework presented in Table 1. Company 2 was already implementing the strategy –function at a level that projects addressing the function were not perceived to add significant value for the company.

4. Description of the innovation management system's functions

The strategy function aims to steer the innovation activities in construction company. It contains four elements. First business strategy is the most important element in the strategy section. During the research process the business strategy was mainly taken as given since business strategy is a starting point for all of the activities of the company. The scope of the projects was in the innovation strategy level. Innovation strategy is formulated based on the business strategy. The innovation strategy aims at facilitating innovation activities that enhance the implementation of the business strategy. Based on business innovation strategy, targets of innovation activity are derived. Then resources are allocated based on the strategies and targets. All of the companies had an existing innovation strategy of some kind. In some projects the strategy was evaluated and updated according to the results of the project in particular. The case companies found target setting especially important in order to successfully implement the three other functions.

The market input function aims to steer the development process and to facilitate effective innovation investment decision-making. The function consists of four elements, which are customer needs, regulation, technology, and competitors. Customer needs can contain for example new customer problems, new breakthrough ideas for R&D, information about budget restriction in the economic sense or the changing preferences of consumption. The regulatory side is especially important in the construction sector as mentioned in the literature overview. This means that regulatory market input is especially important. Regulatory input can contain information about national legislation, the political environment or government subsidy allowances. Technology and competitor project inputs were found very important as well by the companies.

The development process function can be compared to traditional innovation management systems found in innovation management literature. Idea generation can be done both in-house or it can be outsourced. Development of the product and piloting of the product is also included in the development process. It is decided in the utilization phase whether the new innovation is tested in construction projects and whether it is introduced to the market. Further development of the concept at hand can be done based on the results of the pilot project by feeding the information from project to the R&D process. Development process function was found especially relevant by one company that mainly operates at construction product manufacturing.

Competences and resources can be found both in-house or from the outside the company as open innovation theory implies. Outside resources can be utilized via intellectual property acquisitions from other companies. Outside competences and resources can be also obtained by forming partnerships with collaborating companies. This is especially important in the construction sector. One of the companies was especially interested in addressing the problem with fragmented value chains by partnerships that align the interests of different stakeholders. Also company acquisitions were found to be significant for larger companies. Competence can also be acquired from the market by recruiting new talent. Education and training can be organized within the company or bought outside.

The link between the functions is essential. Strategy is the most important function of them all and it guides the other functions. The three operational functions thus aim at implementing both the business strategy and innovation strategy. Development function utilizes the information and resource feed from the three other functions. However strategy guides what kind of information or resources are utilized in the other functions. It was observed during the research process that all of the functions and sub-functions were more or less relevant depending on the company and its strategy. Application the framework in practice can begin from adapting some functions of the framework. However, the strategy function can be considered essential since it steers all of the other functions.

5. Summary of the results

All functions – Strategy, Market input, Competences and resources and Development process – were found to be relevant for the case companies. Especially the function Market input was found to be relevant for the case companies. The function complemented the existing innovation processes of the companies, as it was the function that was missing or that was not systematically implemented in existing innovation processes.

According to the feedback from case companies, implementing the market input function added significant value to the innovation process of the companies. The companies experienced that the market input function brought critical investment decision-making information for finding and investing in innovations that are valuable. In particular, market input function added value for selecting a few innovation investment opportunities out of a larger set of scanned opportunities for a deeper pre-investment analysis before making a final decision. Interestingly the projects that were related to strategy, development process or competences and resources did not generate significant new value for the companies. It seemed that existing innovation processes of the companies were already in acceptable level.

6. Discussion and conclusions

The main finding of this study is that construction sector companies can utilize and benefit from innovation management systems. The system developed in the present study seems to provide construction sector companies a structured way to manage their innovation activities. Especially market input function added the most value for existing innovation management process of the project companies. After the completion of the present study, the market input function has been widely adapted in the Finnish construction sector and applied in more than 120 major industry projects. The system also proved to be successful in integrating various innovation systems that are commonly used in manufacturing industry. However, when generalizing from the results, this study has some important limitations. For example, research applied only to Finnish companies that were relatively large at size.

Further research topic could be doing a follow-up study for the companies that reviews the results of adapting the innovation management system. Another interesting research topic based on this paper would be testing the innovation management system as a construction company management system instead of concentrating merely on innovation management.

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Examining Happiness: Towards Better Understanding of Performance Improvement

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Abstract

It is well accepted that happiness can provide immense motivation for someone to achieve higher performance. Generating happiness in the workplace is one way of empowerment to induce productivity. This empowerment has been widely studied and explored in many industry sectors but only limited studies have been done for construction industry. This research tries to enrich this topic by conducting study to engineers of construction firms. In the study, in addition to happiness, psychological well-being and stress were included to cover better understanding of the subject. For the performance side, two perspectives were considered: a self-performance assessment by the engineers and a performance assessment by engineer's supervisor (project manager). A total of 114 engineers and 21 project managers from 21 construction sites in Sri Lanka were surveyed for the purpose of this research. The result revealed that a significant positive strong relationship between psychological well-being and performance can be identified. The same also applied to happiness and performance, only at a lesser degree. As expected, stress had a negative association with performance; however, the degree was only weak and not statistically significant. The study also found that age, marital status, salary, and construction experience have similar and different roles in defining the level of happiness, psychological well-being, and stress at work. For example, single engineers are significantly happier and perform better in their work than married engineers. Meanwhile, years of experience are significantly associated with performance and stress but not with happiness and psychological well-being. Therefore, it is important to understand how happiness, psychological well-being, and stress levels are differently associated with the socio-economic and experience of engineers. Each factor may relate uniquely in defining the happiness, psychological well-being, and stress at work as different level of engineers has different concerns, and needs different motivational approach to improve their performance.

Keywords: happiness, empowerment, engineer, motivation, performance.

1. Introduction

Happiness is a vast topic which has been a foundation for many researches [1,2,3,4]. There are many definitions of happiness, however, the overall idea of happiness is how much you like what you have or do [1,2,5,6]. Therefore, even if two persons have everything equal, the happiness level may be different depending on how much each individual values what s/he has. It is acceptable to say that everyone who is alive pursuits happiness. People would do a lot of things for happiness, which highlight the important of happiness as an immense motivation to higher performance. An individual would motivate to perform well to keep up the happiness s/he already has or to achieve more happiness.

When discussing happiness and performance, it is important to understand their association with stress and psychological well-being. Measuring psychological well-being and stress provide considerable indication about performance [5,7]. Meanwhile, when someone responds to emotional or mental pressure, stress starts to appear [8], which indicate the link between stress and happiness.

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In a construction project, the increase or decrease in the project expenditure depends on a set of factors, such as construction materials, equipment, construction techniques, labor force and management skills [9]. Construction engineers, who directly manage most, if not all, of these factors, have important roles in defining the cost of the project. Thus, having productive engineers will minimize the construction cost and also will increase the quality of the project. The question is: how to make engineers in construction industry perform well?

Even though there are many research studies on the relationship between happiness and performance of employees, most studies focus on industries other than construction. Therefore, it is interesting to explore this relationship for construction engineers as construction projects have unique nature than other industries, where each project has different location and may be far from the previous one, which demand mobility or temporary residence of engineers away from their homes to do their job. Construction engineers may need to work in a different environment from the previous assignment and deal with new members of the team in executing the work. These add challenges in their work and life. With the above uniqueness of construction industry, this study tries to enrich the literature by examining the factors that define happiness for construction engineers so proper empowerment approaches can be considered towards improving their performance at work.

2. Literature on happiness, performance, stress and psychological well-being

When the desire is to get higher performance, the first thing that comes up is money. There is more motivation power in money and giving money as a reward will increase workers performance individually [10]. But, is money the only thing which has motivation power? In a survey by Michael [2], half of the workers would like to change their job even if their salary is lower than what they have because it satisfies their needs. He also found that the top two reasons that a worker leaves his job are manager and dissatisfaction with the work content. This indicates that there are other things besides money satisfy worker's needs.

Findings from research studies have shown evidences to support that happiness has considerable relationship with performance [1,2,5,7]. An effect on worker's productivity, creativity, commitment and collegiality can be drawn from happiness [11]. Furthermore, when there is a good mood, which is a proxy for happiness, people will have more positive attitude towards each other's, provide greater helpfulness and generosity, and generate better and more original problem solving [2]. Happiness has specific domains, even though some have been described differently. The factors influencing happiness may vary depending on the scope of the study. Measurement of happiness for a whole country, such as the research on gross national happiness (GNH) index [12], where the measurement has nine domains with 33 indicators, may not be an efficient approach for measuring happiness of employee in certain industry or in a company.

When it comes to psychological well-being, comfort, pleasure, enthusiasm, vigor, and placidity can be used as indicators to measure the psychological well-being [5]. Research evidence has shown that a positive spirit of camaraderie improves comfort, pleasure and placidity of employees [5], which indicates that support in dealing with work difficulties and challenges, motivation from the group and good social relationship are important [13]. In the effort of increasing psychological well-being of enthusiasm and vigor, better opportunities for personal development and learning can be provided at work to empower employees and make them feel that their jobs are rewarding and motivating.

Someone is in stress when s/he is not capable to manage his/her job pressure [14]. Daniels and Guppy [15] found that employees with low level of job satisfaction and psychological well-being are mostly likely to be stressful at work. One study found that the absence of trust and creditability of the supervisor and the lack of balance between work and family seriously contribute to stress at work [5]. When supervisors do not provide enough support to employees by giving proper guidance and direction at work, this generates uncertainty in executing the work and increase stress [15]. Stress may not have direct influence to the performance, however, with lower psychological well-being due to stress; performance can be expected to decrease [5].

3. Methodology

A questionnaire survey was developed to measure the levels of happiness, psychological well-being, stress, and performance using five-point Likert scale. The questions to measure the levels were adapted mainly from two sources: Rego and Cunha [5] and Ura et al. [12]. A total of 10 domains (teamwork, trust and credibility of leaders, open and frank communication with leaders, opportunities for learning and personal development, standard of living, fairness/justice, work-family conciliation, good project, health, and time) consisting of 36 indicators were used to measure happiness of respondents. The importance of each domain was also asked to be used as a weight in calculating the happiness. The frequencies that respondent feels comfort, pleasure, enthusiasm, vigor and placidity in the last three months, which represent affective well-being, were used to determine the psychological well-being. The level of stress was assessed from three questions related to the job.

Measurement of performance was conducted from two perspectives. The first one is self-assessment of individual performance and the second one is assessment from supervisor. Three questions were designed to evaluate the self-reported individual performance and four questions were used for the assessment from supervisor. Questionnaires were distributed by hand to 116 engineers of 21 construction sites in Sri Lanka. Consequently, for the performance assessment, 21 project managers were requested to provide their assessment on the relevant engineers. This process was carried out when collecting questionnaires back from engineers to get their identifications. It is important to emphasize that none of assessment was disclosed to engineers as the purpose is solely for research. Two out of 116 returned questionnaires were found to be invalid so in total 114 responses were used for the analysis.

4. Results and discussions

Respondents of the survey were dominated with male engineers. There are slightly more married engineers than single engineers even though the portion of young engineers (30 years and below) are higher than engineers above 30 years old. Detailed characteristics of respondents are presented in Table 1. The sub-categories for age, salary, construction experience and current project experience were not the same as the original sub-categories in the questionnaire. Those shown in Table 1 were simplified from the original questionnaire by grouping some sub-categories into one so meaningful comparison between sub-categories can be statistically analyzed.

Table 1. Characteristics of respondents.

Category	Sub-category	Number	Percentage
Marital status	Single	53	46.5
	Married	61	53.5
Age	30 years and below	65	57
	Above 30 years old	49	43
Gender	Male	101	88.6
	Female	13	11.4
Salary	Low (Rs 50,000 and below)	44	38.6
	Middle and High (Above Rs 50,000)	70	61.4
Construction experience	2 years and below	45	39.47
	3-10 years	33	28.95
	Above 10 years	36	31.58
Current project experience	2 years and below	81	71.05
	Above 2 years	33	28.95

4.1. *Relationships between happiness, performance, psychological well-being and stress*

In analyzing the relationships between happiness, self-reported performance, performance assessment by supervisor (performance), psychological well-being, and stress, Pearson Correlation tests were carried out. The results are presented in Table 2.

Table 2. Correlations between happiness, performance, psychological well-being, and strees.

	Performance	Self-Reported Performance	Psychological Well-being	Stress
Happiness	r = 0.478** Moderate (+)	r = 0.187* Weak (+)	r = 0.357** Moderate (+)	r = 0.006 No relationship
Performance		r = 0.329** Moderate (+)	r = 0.63** Strong (+)	r = -0.123 Weak (-)
Self-Reported Performance			r = 0.315** Moderate (+)	r = -0.119 Weak (-)
Psychological Well-being				r = -0.143 Weak (-)

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

As shown in Table 2, performance has moderate positive correlation with happiness and strong positive correlation with psychological well-being. Both relationships are significant at the 0.01 level. This indicates that psychological well-being has more roles in defining performance than happiness. From the value of coefficient of determination, nearly 40% of the performance of engineers can be explained by their level of psychological well-being. Meanwhile, happiness can only explain less than 23% of the performance achieved by engineers. These findings are in line with the findings of Warr et al. [16] and Amabile and Kramer [11] in their research to employees of industries other than construction. Interestingly, even though happiness and psychological well-being also have significant relationships with self-reported performance, the degree of association is less than to performance.

The results also show that there is a significant positive relationship between happiness and psychological well-being with moderate degree of association. Psychological well-being can only explain less than 13% of happiness, which indicates that there are other factors that contribute more in defining happiness than psychological well-being. Surprisingly, this study reveals that although stress has negative relationships with psychological well-being and performance, which are reasonable, the relationships are not significant. It is also interesting to note that stress has no correlation with happiness in this study.

4.2 Effects of socio-economic factors and experience

For the purpose of having better understanding about happiness, psychological well-being, stress, and performance, it is important to analyze whether socio-economic and experience of engineer (please refer to Table 1) may contribute on defining the level of the above factors. With this understanding, it is expected that proper strategy and approach can be developed in the effort of increasing performance of engineers depending on their socio-economic and experience. Due to the space limitation, the test results are not provided in this paper.

4.2.1 Marital status of the engineers

In analyzing whether married and single engineers have difference perceptions on happiness, performance, psychological well-being, and stress, independent sample t-test was performed. The result shows that there is a statistically significant difference in happiness (t=-2.462, p=0.015) and performance (t=-4.335, p=0.000) between the married and single engineers at the 0.05 level, where single engineers are happier and consequently, perform better in their work than married engineers. When the confidence level is reduced to 90%, the difference is also significant for psychological well-being (t=-1.722, p=0.088) and stress (t=1.668, p=0.098). Again, with single engineers has higher level of psychological well-being and lower level of stress than married engineers, which are consistent with the findings from previous studies [17,18]

4.2.2 Age of engineers

The statistical test indicates that junior engineers (30 years and below) have significantly higher happiness (t=3.195, p=0.002) and performance (t=3.508, p=0.001) than senior engineers (above 30 years old) at the 0.05 level. In a similar case as the marital status, the psychological well-being is significantly different only at the 0.1 level with junior engineers show higher level of psychological well-being (t=1.698, p=0.092) than senior engineers. For the stress at work, junior engineers perceive significantly lower level of stress (t=-2.281, p=0.024) than senior engineers. It is acceptable to assume that young engineers, who most likely are still single, have less responsibility than senior engineers. Additionally, due to the age, junior engineers may have higher working capacity than their senior, which is supported by the research of Kahneman [19].

4.2.3 Salary of engineers

In terms of salary, it is found that middle and high income salary engineers have significantly higher level of happiness (t=-2.138, p=0.0350), performance (t=-4.021, p=0.000), and psychological well-being (t=-2.688, p=0.008) than low income salary engineers. These findings support the study of McBride [1] where he found that money influences satisfaction (happiness) and this will lead to the increase of performance and psychological well-being. On the other hand, stress (t=1.381, p=0.170) does not take any side. Stress can happen to an engineer regardless s/he is a low income earner or a middle and high income earner. No significant difference can be detected.

4.2.4 Construction experience of engineers

Based on the years of experience in construction projects, respondents are classified into low (2 years and below), average (3-10 years), and high (above 10 years) for the comparison analysis. One way ANOVA test was conducted to analyze the difference and the result shows that there are significant differences among these three groups of engineers for performance (F=4.910, p=0.009) and stress (F=3.166, p=0.046).

Tukey post hoc test was applied to identify the difference among the groups. The test identifies significant difference in performance between engineers with low experience and high experience. Surprisingly, low experienced engineers received higher performance than high experienced engineers. This unexpected finding was intriguing. When the self-reported performance between these two groups was examined, the result was not consistent. For self-reported performance, the groups mean value indicates that high experienced engineers reported higher performance than low experienced engineers; even it is not significantly difference. As the performance was assessed by the project manager (PM) of the relevant engineers, they were inquired to find out the reasons. The responses confirmed the finding mainly because of the hard work nature of low experienced engineers due to their age and keenest to learn for their career. One of the project managers even commented that low experienced engineers work more than what is worth for their salary because they want to gain experience for their career.

The post hoc test also identified significant difference in the stress level between low and high experienced engineers. Engineers with high experience face more stress at work than low experienced engineers. Higher expectation and responsibility assigned to high experienced engineers may contribute to this finding.

5. Conclusions and recommendations

This study reveals that there are significant positive relationships between happiness, psychological well-being, and performance with the strongest relationship can be observed between psychological well-being and performance. Therefore, if a Sri Lankan construction company plans to improve its engineers' performance, the company management needs to focus on the factors that bring good psychological climate in the project site. The good news that can be concluded from this research is that stress experienced by engineers at work can be expected not to affect performance as the stress level has no significant association with happiness or psychological well-being.

Based on the socio-economic and experience analyses, performance is considerably influenced by marital status, age, salary, and construction experience. It is found that single engineers perform well than married engineers. Performance of engineers is also reflected in their salary where better performed engineers are associated with higher salary. One interesting finding is related to the performance of junior engineers who are identic to low experience that received significantly higher assessment than senior engineers, who are rich in experience. The spirit of learning new things in actual construction projects, supported by their age, has motivated junior engineers to work hard for their future. With this, as also suggested by one of the project managers who are respondents in the data collection of this research, hiring more junior engineers or trainee engineers, while keeping only a few senior engineers for technical aspects, may produce better performance for the success of the project. On the other hand, this indicates that solutions to improve performance of senior engineers need to be considered. For this purpose, factors that significantly define happiness and psychological well-being of senior engineers need to be analyzed before a recommendation can be proposed.

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Possibility of Using Value Engineering in Highway Projects

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Abstract

The paper deals with the possibility of using value engineering in highway projects. The reasons for criticizing highway projects are usually three. Firstly, they do not achieve expected project goals, secondly, project delivery is not within a reasonable amount of time, and finally, costs are not in line with their budget limits. The author believes that value engineering methodology can help to find ways to improve solutions to these problems by balancing cost, schedule, and scope through the generation of innovative alternatives. It was found that a project can significantly save on costs and improve performance of project functioning by using the appropriate value engineering process at the right time. The paper summarizes the benefits and effectiveness of the value engineering methodology along with recommendations.

Keywords: cost, highway construction, public projects, value engineering (VE)

1. Introduction

Programs in the public works sector such as highway construction are being criticized for delivering projects that fail to hit the following targets:

- Expected project objectives
- Delivery within a reasonable amount of time
- Costs no more than their budgeted amounts

In order to avoid this, care must be taken to achieve a reasonable number of highway projects that meet the expected project goals, are completed in time, and do not exceed the planned costs. Performance-based value engineering, modified for public works applications, can help achieve this. There is the need for a project management tool that efficiently identifies and balances project scope with the schedule and costs. Furthermore, project managers need to identify and analyze a large quantity of project alternatives with an appreciable variation in scope, schedule and cost.

Escalating construction and maintenance costs, combined with reduced revenues, have led to an increased interest in value engineering by government transportation agencies [1]. All national agencies in Asia have national regulations mandating that certain projects have be value analyzed. In the USA, the Value Engineering Final Rule requires value engineering analyses of projects on the National Highway System (NHS) which receive Federal assistance reaching an estimated total cost of $50,000,000 or more, also bridge projects on the NHS receiving Federal assistance reaching an estimated total cost of $40,000,000 or more, and it provides for VE analysis guidance on projects [2]. There are no similar regulations in the Czech Republic.

Value Engineering helps a project to meet the customer’s need for cost efficiency within a short timeframe. It is important to realize that VE tools focused on the construction sector, particularly public works construction projects, should have greater emphasis on project scope, as this aspect of public works is usually the challenging aspect of project development. VE study looks for ways to improve solutions to a problem. It is a function-oriented, systematic, team approach, used to analyze and improve value in a product, facility design, system, or service. It offers a powerful methodology for solving problems and reducing costs while improving performance and quality. Value engineering studies can provide measured balance in cost, schedule, and scope by generating multiple innovative alternatives. This requires a motivated team of professionals in cooperation with project stakeholders stimulated and guided by such an appropriate process.

The main goals of this paper are to suggest a performance measurement based on the VE method for public projects and to summarize the benefits of the proposed methodology.

2. Literature review

Value Engineering is a conscious and explicit set of disciplined procedures designed to seek out optimum value for both an initial and long-term investment. First utilized in manufacturing industry during World War II, it has been widely used in the construction industry for many years.

The Society of American Value Engineers (SAVE) was formed in 1959 as a professional society dedicated to the advancement of VE through a better understanding of the principles, methods, and concepts involved. The Society of American Value Engineers defines VE as the systematic application of recognized techniques that identifies the function of the product or service, establishes a monetary value for that function, and provides the necessary function reliably at the lowest possible cost. Therefore, the purpose of a systematic VE approach is well demonstrated when the user is able to define and segregate the necessary functions from the unnecessary functions and thereby develop alternative means of accomplishing the necessary functions at a lower total cost [3].

VE in the construction industry is mainly an organized effort to challenge the design and construction plans of projects to provide the required facility at the lowest overall cost consistent with requirements for performance, reliability, and maintainability [4].

Research [5] emphasizes the “VE Job Plan” as an organized and systematic approach tool and is the key to success in VE studies. The job plan is the road map for defining the required task in determining the most economical combination of functions to complete the task. It is through the job plan that the study identifies the key areas of unnecessary costs and seeks new and creative ways of performing the same function.

Other research [6] defines VE by what is true and what is not true about the VE concept. They state that VE is a systematic and multi-disciplined management technique. On the other hand, it is not a design reviewing, cost lowering, or quality control process. The Function Analysis System Technique (FAST) diagram is a powerful tool that helps to organize the random listing of functions by answering the questions: How? Why? What does it do? What must it do? This helps the VE team to develop many verb-noun functions’ structure and their interrelationships. Also, FAST diagrams aid in the identification of basic function and scope [7].

However, little research has indicated the importance of a performance measurement-based VE methodology for public construction projects. One study [1] demonstrates how a performance-based value engineering methodology helps save time and money and increases that functional performance. The objective of this study was to upgrade and expand existing facilities and systems on an express highway linking Seoul to Pusan. The VE study generated several innovative alternatives capable of saving up to 50% of project costs and also increasing performance and value from the baseline project plan.

The design stage is the key stage of investment control in highway engineering. The advantages and disadvantages of design scheme quality directly influence the whole effect of project investment and application. Another study [8] verifies the reliability of applying value engineering in optimizing a design scheme of highway engineering using an actual engineering example. How to apply the theories and methods of value engineering in construction project is shown in [9]. In the construction of the road during the design process, the construction costs were reduced and the construction period was shortened by using value engineering methods. This paper analyzes loss of control in a highway investment at the design stage and puts forward some methods to control the cost of a highway for consideration in a Design Department, such as promoting quota-designs, optimizing a design project, enhancing design management and so on.

According to the Federal Aid Highway Program (USA) [2], value engineering is defined as the systematic process of review and analysis of a project, during the concept and design phases, by a multidisciplinary team of people not involved in the project, and that is conducted to put forward recommendations for providing a) the needed functions safely, reliably, efficiently, and at the lowest overall cost; b) improving the value and quality of the project; and c) reducing the time to complete the project. The successful application of the VE process can contribute measurable benefits to the quality of surface transportation improvement projects and to the effective delivery of the overall Federal Aid Highway Program. The Value Engineering Final Rule was published in 2014, and this Final Rule removes the VE analysis requirement for projects delivered using the design/build method of construction, provides VE analysis guidance for projects delivered using the construction manager/general contractor (CM/GC) method of project delivery, and increases the project thresholds for required VE analyses to:

- Projects on the National Highway System (NHS) receiving Federal assistance with an estimated total cost of $50,000,000 or more
- Bridge projects on the NHS receiving Federal assistance with an estimated total cost of $40,000,000 or more.

Their web site describes the FHWA's VE program, discusses many subjects crucial to the administration of a successful VE program, and attests to the program's benefits through the compilation of annual accomplishment reports and descriptions of successful practices and VE analyses. The FHWA's VE program applies to the Federal Aid Program under which the funds authorized for Federal aid highway acts are distributed to States for projects developed and administered by State Departments of Transportation (DOT). The FHWA annually collects information on VE accomplishments within the Federal Aid and Federal Lands Highway Programs. The following Table 1 summarizes recent savings realized by conducting VE.

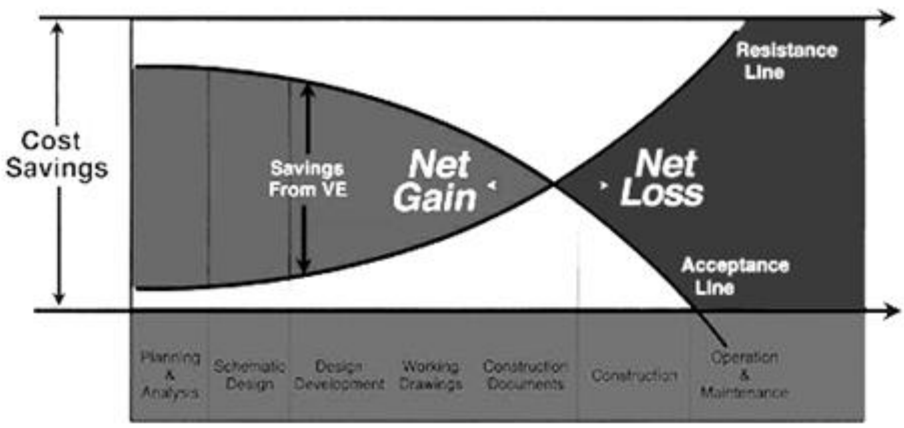
Table 1. Summary of past VE savings

Year	2014	2013	2012	2011	2010
Number of VE Studies	215	281	352	378	402
Cost to Conduct VE Studies and Program Administration	\$8.7 M	\$9.8 M	\$12.0 M	\$12.5 M	\$13.6 M
Estimated Construction Cost of Projects Studied	\$20.9 B	\$23.0 B	\$30.3 B	\$32.3 B	\$34.2 B
Percent of Project Cost Saved	8.32%	5.01%	3.78%	3.12%	5.79%
Return on Investment	200:1	118:1	96:1	80:1	146:1

3. Value engineering in construction projects

Value Engineering is not a design/peer review or a cost-cutting exercise. Value engineering is a creative, organized effort, which analyzes the requirements of a project for the purpose of achieving the essential functions at the lowest life cycle cost (LCC). Through a group investigation, using experienced, multi-disciplinary teams, value and economy are improved through the study of alternative design concepts, materials, and methods without compromising the functional and value objectives of the client. VE can be applied at any point in a project, even in construction. However, typically the earlier it is applied the higher the return on the time and effort invested – see Fig. 1 [4]. The three main stages of a project and a VE application are described below.

Fig. 1. Potential savings from value engineering application.



3.1. *Planning*

At the planning stage of development, there are additional benefits to be derived from a Value Engineering Workshop. An independent team can review the program, perform a functional analysis of the project, obtain the owners and users definition of value, define the key criteria and objectives for the project, verify the proposed program, review master plan utility options, offer alternative solutions, and verify the budget.

3.2. *Design*

Design is the stage that most VE participants usually become involved, the point at least when the design has made it to the schematic stage. The primary tool available to the VE team is the Workshop. The Workshop is an opportunity to bring the design team and client together to review the proposed design solutions, the cost estimate, and the intended implementation schedule and approach, with a view to implementing the best value for the money. The definition of what is good value on any particular project will change from client to client and project to project. The five-step "VE Job Plan" is followed, as prescribed by SAVE International:

- Information Phase (understanding the background, analysis of the key functional issues – the cost and impacts associated with function)
- Creative Phase (ways to provide the necessary function at a lesser LCC - improved value for client)
- Analysis Phase (criteria definition for evaluation, ideas analysis, weighted evaluation)
- Development Phase (ideas are expanded into workable solutions – design change, evaluation of advantages and disadvantages, cost comparison, LCC calculation, comparison to original design)
- Presentation Phase (recommendations, key cost impacts).

3.3. *Construction*

During construction value engineering is still possible. Contractors can be provided with monetary incentives to propose solutions that offer enhanced value to the owner, and a share in the financial benefits realized. Clearly the owner must consider contractor-generated proposals very carefully, from both a life-cycle perspective [10], and a liability perspective. The team must be brought in to the decision-making process to agree to the proposed change in order not having any negative impact on the overall design and project function.

Value Engineering is not only beneficial, but essential because:

- The functionality of the project is often improved as well as producing impressive savings, both on initial and Life Cycle Cost
- A "second look" at the design produced by engineers gives the assurance that all reasonable alternatives have been explored
- Cost estimates and scope statements are checked thoroughly assuring that nothing has been omitted or underestimated
- It assures that best value will be obtained over the life of the project

4. Performance measurement- based value engineering

One of the problems with studies on public highway projects is the tendency for them to become a "cost-cutting" tool instead of a value-enhancing tool [11], [12]. Since costs are reported only at the conclusion of each study, there is no mechanism for weighting the value of the project costs that were cut against the project scope and project delivery components that accompanied these costs. Using value engineering and the performance measurement application in VE can help to optimize a project plan by minimizing cost and maximizing function performance. Project stakeholders quantify what and how well the project delivers project scope, schedule, and costs by measuring the impact and rating the effectiveness of the alternatives along with the performance measurement criteria. The reasons why we need to measure project performance for public works can be given. It brings transparency to all project issues for the project stakeholders, it handles "conflicting" project criteria, it addresses technical issues using quantitative or qualitative parameters, and it improves the probability of delivering a project that serves the community with optimal project value. Below, the formula shows the relationships between value, performance and life cycle cost.

$$V_i = \frac{P_i}{LCC_i} \tag{1}$$

Where:
V_i … Value of improved alternative *i*
P_i … Performance of improved alternative *i*
LCC_i … Life cycle cost of improved alternative *i*

In the VE process, project stakeholders identify the performance criteria, establish their relative weights, and then rate the current project. The VE team establishes the performance of the new alternatives as compared to the current project's performance, and project stakeholders verify the performance ratings for the VE alternatives. Determining the project performance criteria is an important process for measuring the project functions. Qualitative and quantitative parameters should be used to increase the objectivity of the application. Proposed criteria for highway construction are quality and safety, constructability, public-friendliness, environmental-friendliness, socioeconomic factors, operational efficiency and maintainability, and project management considerations. After the project performance criteria and relative importance (weightings) are determined, stakeholders define the performance criteria parameters by identifying the units of measurement for each of the performance criteria and by establishing a range of acceptable values for these criteria. The selected sets of alternatives are compared against the original design concepts. The total performance rating is divided by the total project life cycle cost to produce a value index (1), and the difference between the value indices of the original design and the alternatives is expressed as a Value Improvement.

5. Conclusion and Recommendation

The quality and cost of highways and other projects in the public works sector can benefit by the application of value engineering methodologies. Specifically, the VE methodology provides for analyzing the project objectives and attributes, which, in turn, focuses the development of alternatives in the value study. Government agencies that apply value engineering to their construction programs can achieve the following benefits: resolve technical problems on complex projects, gain additional technical expertise, give emphasis to efficient use of resources, improve project performance and achieve cost savings. Project performance measurements quantify the quality of project objectives and the timeframe in which they are delivered, which in turn allows the project value to be determined. Through VE program use in the public sector, significant improvement in project performance and cost savings has been experienced. Improving the relationship between the project performance and project life cycle costs has been a major benefit to public project managers. These savings have been extended into other public projects, a real value for the taxpayer. Most importantly, using VE could accelerate construction because it creates a consensus-building foundation. VE studies carried out in the public sector have allowed for the development of consensus on what the project scope, budget, and delivery should be. This consensus has been formed with project stakeholders, such as local governments, transportation and regulatory agencies and the communities involved or affected.

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Proposal for Practical Application of a Project Ranking Criteria

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Abstract

Project ranking is a common management tool in the business planning process for organizations that face various resource bottlenecks, which, in most cases, is the available capital expenditure (*CAPEX*). Should this situation occur, the management board of the company must prioritize the projects to select a portfolio that promises the maximum added value with respect to the given bottleneck. "Value", however, is not only considered in terms of money. One may also find minimally monetizable benefits that are in compliance with strategic statements, credibility, or organizational development. Thus, it is essential to carefully select the criteria of project ranking. After reviewing the management science literature, we concluded that setting up Financial, Strategic, Stakeholder and (organizational) Learning Criteria groups gives a more sophisticated solution for the project ranking exercise and can be recommended for business entities.

The definition of sub-criteria within the criteria groups above is, however, business specific. Our study takes the oil and gas exploration business as an example. The most critical phase of the exploration process is drilling for new fields because geologists usually bring about more opportunities than what is allowed by the available *CAPEX*. The sub-criteria discussed in our paper are therefore exploration-drilling specific but may orientate managers of other businesses when they attempt to define their own criteria system. The sub-criteria include profitability, risk diversification, upside potential, internal and external stakeholder, and various learning opportunity approaches.

In addition to criteria definitions, it is equally important to quantify the weights belonging to each ranking criteria. As the weights should reflect management preferences, a teamwork approach is recommended for the quantification. We also suggest application of the Analytic Hierarchy Process (*AHP*) methodology in the ranking exercise. Our paper concludes with a case study in this respect.

Keywords: project ranking criteria; exploration specific criteria; application of analytic hierarchy process; project portfolio selection.

1. Introduction

The ubiquitous project portfolio approach has had a significant impact on modern organizations. Managing the rapidly growing number of projects has become one of the most important tools for achieving the strategic goals of an organization, and as Olsson (2008) and Teller and Kock (2013) argue, in a project portfolio environment, the practice of single project management (*SPM*) has become increasingly insufficient, while project portfolio management (*PPM*) is recognized as one of the most crucial challenges of organizations [13,21].

In our article, we use the definition of project portfolio based on the approaches of Archer and Ghasemzadeh (1999) and Martinsuo and Lehtonen (2007) [3,9]. By this definition, the portfolio is a group of rival projects striving for scarce resources carried out under a single sponsorship and management of an organization in line with the firm strategy. Recently, the portfolio-wide perspective of project portfolio management has gone well beyond single project management that focuses only on the processes of one project and ignores the synergistic effects of the others.

Project portfolio management is about managing multiple projects, programs, sub-portfolios, and operations as a group to achieve strategic objectives (PMI, 2013) [15]. The first step of *PPM* is project portfolio selection (adding, taking out, and prioritizing projects) including periodic activities that involve selecting from available projects and

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meeting the organization's objectives according to constraints (see e.g., [3]). Thus, as Nowak (2013) argues, project portfolio management is a recurring dynamic and interactive decision process, whereby the portfolio must be constantly updated and revised [12]. The result of this process is a constantly available well-selected and ranked set of projects.

In the literature, there are two distinct directions of research on selecting project portfolios [12]. In the first group, there are articles providing general recommendations with few systematic procedures specifically addressed to practitioners. The second group includes quantitative decision support techniques mainly dedicated to researchers. Multiple criteria should be taken into account to select the right projects at the right time, and recently, a significant number of studies have become available that address the methodological tools for this [1,5,6,8]. These sources provide complex, formal mathematical solutions for multiobjective cases in project portfolio selection, but apart from the thorough operational issues, the criteria selection is not addressed. These techniques employ sophisticated computation tools, but the models often oversimplify the problem.

The proposed criteria hierarchy is to be developed for the exploration segment of the oil and gas industry, in which project portfolio selection is a common management task of the business planning process; at the same time, it can shape the business performance of the oil company in the longer run. The practitioners can obtain a tool that takes arbitrary criteria into account as well, and helps with the automated decision-making process related to project portfolio management. It is a significant step forward, because the management can be relieved of their daily routine tasks because they can build the appropriate portfolio in a controlled and consistent way using the proposed technique. The paper provides an integrated ranking criteria system based on both financial and non-financial elements.

2. Project Portfolios in the Upstream and the Portfolio of Exploration Drilling

The petroleum upstream business involves the management of subsurface petroleum resources through the execution of sequential projects. In fact, it is a value chain that starts with the mapping of potential hydrocarbon accumulations and ends with the production of reserves. Phases of the chain are composed of projects that are distinctively isolable by their technical contents, management characteristics and objectives. The first phase in the sequence usually is a seismic survey targeting to delineate drillable geological structures later on, commonly referred to as prospects. From the perspective of petroleum resources, seismic surveys are prospect-mapping projects resulting in the estimation of Prospective Resource Volumes (for petroleum resource categorization, classification and nomenclature, please see [16]) and the assessment of the underlying geological risks [14,17,18]. In case of the successful delineation of the potential petroleum bearing structures, the sequence continues with a prospect-drilling project, also known as exploration (wildcat) well drilling. The project has two possible outcomes: The successful case results in the discovery of Contingent Resources, while in the unsuccessful case, the well is qualified as commercially dry. In the latter case, the company may contemplate quitting the exploration license or look for other opportunities within the exploration area (in our approach, this means the start of a new project, either prospect-mapping or prospect-drilling). Contingent Resources are, however, subject to further maturation. The subsequent appraisal projects may include additional seismic delineation, well drilling and/or long-term test production of the Contingent Resources. The appraisal project results in the quantification of the Undeveloped Resource Volume of the accumulation. The commercial parts of the Undeveloped Resources are the Undeveloped Reserves. One of the criteria of the commerciality of reserves [16] is the economic viability (i.e., positive *NPV*) of a field development project, which aims to mature the Undeveloped Resources into the Developed Resources category. (Similar to Undeveloped Reserves, Developed Reserves are commercial subsets of Developed Resources). The final phase of the chain is the production of the Developed Resources. (For the sake of integrity, we have to mention that field development projects can be subdivided into green-field and brown-field production intensification projects. This sophistication does not bias the description of the value chain above, as both green- and brown-field developments target Undeveloped Resources – even if it is considered in the brown-field case as additional volume of the yet produced resources.

At the business planning stage, prospect mapping, prospect drilling, appraisal and field development projects represent disjunctive phases of the overall upstream value chain (the last phase, production, is not considered a project-based activity). Their subjects, in terms of petroleum resources, are of different maturity categories. Thus, on the platform of business planning, the upstream organizations manage four distinct portfolios in which projects with similar characteristics are in fact competitors to each other. The setting of the optimal composition of the overall upstream portfolio takes place on the platform of strategic planning, which is an exogenous variable in our article. With this statement we argue [10], who weighted the *DCF* distributions of successful and failed attempts with the discrete probability of success and failure. They concluded that the standard deviation of *NPV* (or *ENPV* and *EMV*, as well) of such projects is higher than of those in which there is no branch of failed attempts (e.g., the field development in the oil industry). The companies strive to eliminate the risk of failure by keeping market portfolio of research projects, which is difficult to achieve. Our model assumes that the strategic level decision allocates the "strategically optimal" capital expenditure (*CAPEX*) for each project portfolio. The strategically determined *CAPEXs* might become bottlenecks if the projects proposed by the relevant business units require more than the available budget.

In the given situation, the portfolio managers are compelled to decide the projects that do not survive budget cuts and are therefore cancelled or deferred. The competition between projects is usually the most severe in the prospect drilling project portfolio because drilling opportunities most likely exceed the numbers of other projects. At the same time, prospect mapping, appraisal and field development projects are rather "pre-determined". The seismic surveys with relatively low *CAPEX* requirements are the first steps in the concession work program, and therefore, it makes no sense to cancel them right after the concession agreement with the host government is inked. Although appraisals and field developments are usually costly, they offer early sources of cash, which encourages management to put up the money for all economically viable projects.

Among prospect drilling projects, however, ranking and operational portfolio selections are definitely critical. The budget requirement of the actual drilling proposals almost always exceeds the *CAPEX* that has been made available by the strategic planning. Farming out concession interests, of course, is an immanent option for the decrease in expenditures, but concession partner involvements can be limited. In this situation, project ranking aims to identify those projects to be cancelled. In our study, we address this scenario. We primarily focus on the formulation of a proper ranking criteria hierarchy and discuss a potential quantification methodology for the ranking exercise itself.

3. Ranking Criteria for the Prospect Drilling Portfolio

In the practice of most oil companies, project ranking is performed with financial metrics. For prospect drilling projects, the key and sometimes only metric is the Expected Net Present Value (*ENPV*). The *ENPV* reflects the risk of failure, which means that – under a certain probability – the drilling bit does not encounter recoverable hydrocarbons. As the chance to find petroleum depends on the favorable outcome of risky geological events in the past, it is commonly referred to as Probability of Geological Success (*PoGS*). Accordingly, the risk of losing the exploration investment equals the geological failure [$P(0)=1-PoGS$]. Based on the principles of decision analysis [7], the *ENPV* is computed as follows (we expanded the equations of [11,17]:

$$ENPV = PoGS \times (PV_{AFD} - C_{EXP}) - P(0) \times C_{DH} \quad (1)$$

where PV_{AFD} is the present value of the future appraisal and field development project (to be launched upon a discovery), C_{EXP} is the (discounted) cost of the successful exploration, C_{12}, is the (discounted) cost of the unsuccessful exploration ("Dry-hole Cost"), *PoGS* is the probability of the geological success, and $P(0)$ is the probability of the geological failure. This approach is practically an extraction of the routine *NPV* calculation. It highlights that the dominant risk factor in this phase is *PoGS*. In fact, discounted cash flows (*DCFs*) are determined for the "successful" and the "unsuccessful" scenarios of the project, and the *ENPV* calculation combines the scenario *DCF* weightings with their probabilities.

Without going into detail, *PoGS* is derived from the geological probabilities of the prospects targeted for drilling. These probabilities are assessed by the evaluation of geological factors such as source rock maturation, recoverable reservoir and seal rock development, trap formulation, timing and migration (for more details, see [14,17,18]).

Ranking by *ENPV* is a common industry practice that results in sorting out the financially weakest projects from the portfolio. However, when the Management Board discusses the exploration business plan, several arguments may be heard on behalf of some weak projects, as follows:

- …the *ENPV* is inarguably low but the project's costs are not dramatic at all…
- …the geological chance is quite high compared to the other projects, and we currently have such few opportunities that nothing could be found if it were dropped…
- …I understand it has a comparatively low *ENPV*, but the risked resource expectation is so high… I am afraid that if it were sorted out, it would jeopardize our strategic resource replacement goals…
- …look, the *ENPV* is low because the economic evaluation could not encounter upside resource potential…
- …the *ENPV* is low due to the relatively high exploration expenditures, but the appraisal and field development will not endanger our liquidity, unlike that project "over the line" which will drive us into bankruptcy in the field development phase…

- …you might consider that if the well is cancelled, we will have to pay the penalty, and what is even worse, we will face a very negative impact on our image…
- …what will our respected concession partner think of us if we quit…
- …this project, unlike others, has practically no operational risk, and in addition, our geologists will benefit from learning new ideas…

The list of similar arguments might be endless. It is a clear demonstration that project ranking must look beyond the *ENPV* by putting in place a more sophisticated criteria system. To establish a sound system, the development of a well-structured hierarchy seems necessary.

Structuring requires that ranking criteria groups are necessary to set up. Once the above views of our fictitious Management Board on project ranking are reviewed, we have to conclude that setting up Financial Criteria is unavoidable. Some questions, however, affect the strategic performance; therefore, we propose creating the Strategic Criteria category. Additionally, it seems reasonable to classify aspects interacting with the exploration projects' business environment into a category named Stakeholder Criteria. Finally, emphasizing the organization's ability to benefit from lessons learned, it is recommended to define the Learning Criteria group. The content of the criteria groups listed is discussed below.

4. Discussion

The main steps of a general *PPM* process (portfolio setup, evaluation, prioritization, selection, execution, etc.) were integrated with more phases by, e.g., [22]. This study, however, mainly concentrates on the mathematical implementation and realization with bi-criteria or multi-criteria analyses. Ballestero and Romero (1996) provided a solution to defining a bi-criteria utility function for portfolio problems to average investors [4]. Gutjahr et al. (2010) formulated a multi-objective optimization model including employee competences and their evolution [6], and Anagnostopoulos and Mamanis (2010) developed a three-objective portfolio optimization model with discrete variables considering further financial components [1]. For the complex ranking problem discussed in the previous chapters, however, the Analytic Hierarchy Process [19,20] methodology has been found eligible because it provides a flexible and multi-objective solution that involves the hierarchy of criteria.

Our study attempts to provide an integrated ranking model combining financial parameters with additional non-financial elements that are important for managing the actual exploration drilling portfolio. In the following, we shall demonstrate the implementation of the *AHP* methodology for the study case of this particular project ranking exercise. The proposed ranking method is based on the four criteria groups discussed above, resulting in the corresponding Criteria Indices: *FI* – Financial Index, *STI* – Strategy Index, *SHI* – Stakeholder Index, and *OLI* – Opportunity for Learning Index. As *FI*, *STI* and *SHI* are further subdivided into various sub-criteria, it is necessary to define a formula that gives the actual Index by weighting the correspondent sub-criteria ranking orders, as follows:

$$\begin{aligned} FI_i &= \alpha_1 \times PI_i + \alpha_2 \times LRI_i \\ STI_i &= \beta_1 \times CRRP_i + \beta_2 \times URRP_i + \beta_3 \times PoGS_i \\ SHI_i &= \gamma_1 \times ES_i + \gamma_2 \times IS_i \\ &\sum \alpha_j = 1; \sum \beta_j = 1; \sum \gamma_j = 1 \end{aligned} \tag{2}$$

where *PI* is the Productivity Index, *LRI* is the Liquidity Index, *CRRP* is the Contingent Resource Replacement Potential, *URRP* is the Upside Resource Replacement Potential, *PoGS* is the Probability of Geological Success, *ES* is the External Stakeholder index, *IS* the Internal Stakeholder index, α_j, β_j, γ_j are predefined weights to be specified by the management preferences, and i reflects a given project.

The second step of the ranking exercise comprises the calculation of the overall Project Priority Index (*PPI*) as the weighted average of Criteria Indices, as follows:

$$\begin{aligned} &PPI_i = a \times FI_i + b \times STI_i + c \times SHI_i + d \times OLI_i \\ &a + b + c + d = 1 \end{aligned} \tag{3}$$

where a, b, c and d are respective weights, also to be defined by the management preferences. The "management preferences" mentioned above can be calculated with *AHP*. Using *AHP*, the relative importance of selected Sub-Criteria or Criteria items (e.g., *PI* versus *LRI* or *FI* vs *OLI*) need to be specified in a pairwise evaluation. The relative importance for each pair is given by the Exploration Management Board of the oil company. The actual input value might be the consensus obtained as the result of teamwork or might be the average of individual inputs supplied by the board members. The weight outputs are calculated as the averages of the normalized relative importance values.

The actual project ranking exercise continues with evaluating the importance of each actual project by all Sub-Criteria, and using the weight values derived with *AHP*, one can compute the Sub-Criteria Indices and the Project Priority Index (see Equation 2 and 3). In our case, the overall ranking of the projects (i.e., the petroleum exploratory drilling opportunities) by their *PPI* can then be used for selecting those for which the cumulative exploration expenditures ($\sum C_{EXP,i}$) do not exceed the exploration *CAPEX* budget defined by strategy.

One possible direction of development of the method described in the research is its extension to more periods, because currently it is static. Another possible direction of development is the application of the criteria system for other industries.

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Linking Central Business Processes of Construction Companies with the Performance of Construction Operations

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Abstract

Many studies have been performed about ways to improve the performance of construction operations, including new technologies, construction methods, and production models. However, not enough attention has been given to the impact of the central business processes and to what would be their required conditions of development to support and promote a high, long-range operational performance effectively. The focus has been mainly on the site level and not at the central business level of a construction company. This study addresses this problem looking first to identify the main central business process of the construction companies and the conditions in which they operate. Second, to the relationships between central business processes and the way those construction operations are performed. The impact of these processes and their characteristics on the production systems used in worksites are being analyzed, including aspects like: culture, governance, people, and information technologies. Finally, the perspective of business process management (BPM) is being adapted to the management of construction companies to check the applicability of this approach to construction and the contribution it can provide to this sector. As a result, it is expected that a new structure of requirements for construction business processes is going to be proposed in order to improve operational performance. The methodology of the study includes an exhaustive literature review, a case study and the application of a survey to a group of construction companies. It can be concluded preliminarily that there is a good operational improvement potential if construction central business processes are carried out in a systematic form and if the management of the construction operations at sites is also aligned with these processes in a more integrated approach.

Keywords: central business processes; construction companies; operations; performance.

1. Introduction

Various problems such as a slow pace of improvement of the construction industry as well as low productivity, profitability, and client satisfaction with de achieved value [1-3], are making the construction industry to lag behind other industries such as manufacturing and services industries [1]. To address this, it is proposed here that it is necessary to integrate business processes of a construction company with a focus on the client [4], on staff training, on promoting innovation, and on having a quality agenda, among other actions [1-3]. These conclusions are reported in various investigations around the world, and the Chilean construction industry reality is no different. There has to be a cultural change [5] and leaders' commitment in order to achieve permanent and effective solutions to these issues [1].

In the construction industry, the project culture has been established over the corporate one [6]. Most of the studies and actions to improve construction companies' performance have focused mainly on projects and operational processes. However, the central office is above the construction company´s projects that direct them according to the strategies and visions set at the higher organizational level. There is an important potential to achieve significant improvements on construction projects and operations through the leaders and business processes at this level. However, this has not been studied in depth yet. It is necessary to understand how business processes at the central office are related to projects´ operational processes and the impact they have or could have on their performance.

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This paper presents a research that is being carried out in order to identify the main business processes of construction companies and to understand how these processes are linked and affect the performance of construction operations and projects. Besides, it is going to be proposed a structure of conditions that these business processes should meet in order to achieve a positive impact on operational performance, aligning construction business processes and projects with company´s strategies and clients.

In the next section a summarized background is presented. Then, the research problem is defined, with a brief description of the research methodology, methods and analysis tools. The main results obtained at the moment are shown. Finally, the conclusions of the actual research progress and a description of the following steps in the investigation are offered.

2. Background

This section presents a brief summary of the literature review related to the research problem. First, organizational and project change, and the different approaches relating them to operational performance are discussed. Then, business processes are explained, with some visions and tools used to manage them, and what has been studied and done at the construction industry at this area.

2.1. *Project vs. organizational level focus*

Changes in construction companies are inevitable and necessary, which must be managed to prevent negative consequences and maximize profits. These changes can be grouped into two major categories: 1) at the project level and 2) at the organizational level [7]. The first ones can be associated with projects' operational processes, which have been extensively studied. The latter, on the other hand, are related to subjects like human resource management, risk management, organizational learning, strategic management, information technology management, quality management and organizational development [7]. This level is associated to the business process at the superior level of construction companies.

In construction companies, the project culture dominates normally over the corporate one [6]. In practice, construction companies are highly dependent on their professionals and temporary collaborators´ skills, as Kazi says [8]. In the same way, the chief executive officer of a local construction company, interviewed by the researcher stated that the lack of a clear supporting system from the top company' level makes each construction project behaving differently according to the characteristics of each project manager in charge.

Since the focus on construction companies´ performance improvement has been put at operational process level, no real analysis has been performed on how to structure the business processed of the construction company so that they can contribute positively to the formalization and effective development of the way that the construction company carries out its projects. For example, improvements have been proposed at the project level on some subjects as processes modeling and simulation, management approaches like Lean and Just in Time, workers´ motivation, tools and equipment ergonomics, information technologies like BIM, among others [9]. Some studies have been done at the local context too on topics like the identification of productive, contributive and no contributive work on construction projects [10], and the identification of operational factors affecting a building construction performance [11]. However, not enough attention has been paid to the impact that the top organizational level of a construction company and its business processes has on projects´ performance, how can this impact, if constructive, be reinforced, and the way both, business and project processes are linked.

2.2. *Business Processes*

Business processes are all companies´ activities that bring together people, technology and information in ways that create valuable outputs, in order to carry out their missions, set goals, measure performance, serve customers and address the challenges that arise while doing so [12].

In general, the literature defines business processes in a common way to all processes that create value, without differentiating between the different levels of the organization in where they are. For this research purposes, it is necessary to distinguish between non-operational high-level or business processes that belong to the central office, from the construction operational processes of projects.

2.3. *Business Processes Management*

Multiple perspectives have been proposed to manage the necessary changes in business processes and to control them. Some of these are: Six Sigma, Total Quality Management (TQM), ISO9000, Business Process Reengineering (BPR), and maturity models like the Capability Maturity Model (CMM), among others [7, 12].

These can be considered as different visions within Business Process Management (BPM), but other sources treat BPM as a separate perspective that emerges from BPR [13].

BPM is a body of principles, methods and tools to design, analyze, execute and monitor business processes [14]. This approach allows to design and manage in a systematic way the business processes, making them more agile, flexible, with more visualization and clear responsibilities, eliminating processes inefficiencies and making them simpler [15]. BPM looks for continuous improvement aligning the processes with the strategic objectives and with a focus on the client [13]. The lifecycle for doing so is shown on figure 1.

Actually, it is hard to find BPM research and applications in the construction industry and only a few companies are considering implementing this system [16]. Some first approaches have been completed with the study of cases, where they show how to identify some processes, adapt supporting IT and general factors to keep in mind in order to implement BPM [13, 15, 16, 17]. In most of the cases these studies have focused on projects´ processes. This approach on business process management has not been applied yet at the top level of construction companies, and how changes can be achieved aligning the central office with the constructions operations, in order to have a positive impact on them.

3. Research problem

The link between central office business processes and the operational performance of the construction projects has not been studied yet. It is necessary to understand the central business processes structure of companies, identify the main ones and their current operating conditions, and find the relationships between them and construction operations. The main hypothesis proposed here is that to achieve greater improvement at the site level it is necessary first to have business processes that provide appropriate conditions and governance at the project management level to facilitate it. Together with this, it is considered that improvement efforts at the site level are of limited impact on projects' performance as many previous studies show.

Based on the above, a structure of conditions that central office business processes should comply to achieve a positive impact on constructions operations as well as an appropriate governance are going to be proposed. It is necessary to adapt approaches such as BPM (Business Process Management) to the construction reality in order to accomplish this.

4. Research methodology

To achieve these objectives, an extensive literature review has been carried out which will continue throughout the research. A case study is one of the main methods of study to be used, with the support of an extensive survey to be applied to construction companies. This is a work in progress, and the final results have not been obtained yet. However, the ones that are shown below are sourced from what has been observed at the company that is used as case of study until now. The research has the following stages:

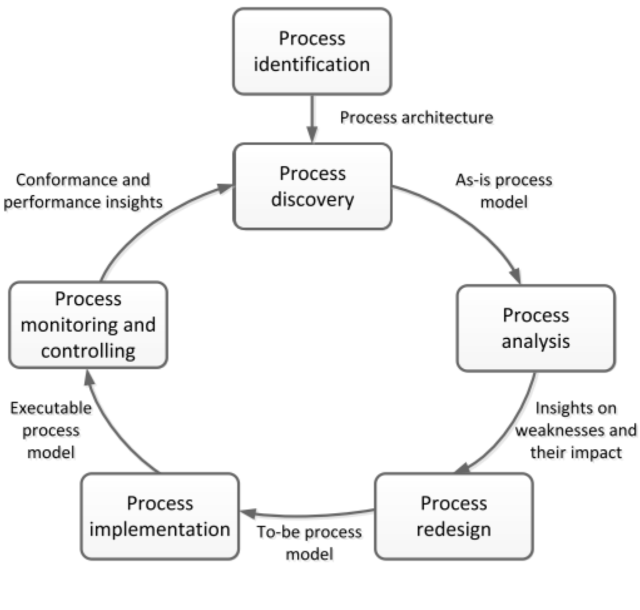

Figure 15: BPM lifecycle [14]

4.1. *Phase I*

It has been sought to define the current structure of the central office main business processes and their operating conditions. From the literature review is has been found out what is the reality of business processes at other industries and which of these processes are the most relevant to the construction industry. At the same time, a study of a case is being carried out to evaluate the main business processes of a specific construction company and to compare with the results from the literature.

The case of study consists in a construction company dedicated to massive housing construction. It has two projects in execution at the moment. Its organizational structure is simple and has less than 200 employees, characteristics that represent the majority of the Chilean construction companies. In this case, project managers and the central office personnel are going to be interviewed in order to see the structure of the main superior business processes, the perceptions they have on the influence of these processes over the construction operations, and the operational performance problems that could be linked to them.

Frequency analysis of the responses and cause-effect Ishikawa diagram are going to be used to model and associate the operational performance main problems with the construction company business processes that would be contributing to these problems. In this way, business processes that have the major influence on projects operational performance at the case of study are going to be identified.

4.2. *Phase II*

Given the above results, links between operational performance and the maturity or development level of these business processes are going to be determined in a qualitative way.

At this stage, a survey is going to be applied to some construction companies with similar characteristics to the case of study. It will be distributed in an electronic format so as to avoid unanswered questions and to have shorter response times. It will be directed to central office management and high-level project management staff. The questions will be closed-questions, with a Likert scale from 1 to 7. It is pretended to identify the perception that high level staff have about the impact that each earlier identified business process has on project operational processes performance.

A frequency analysis will be done, comparing the answers given by the personnel at the central office and at projects. Besides, an ANOVA analysis will detect the main business processes that impact on the operational performance. Finally, the results are going to be compared with the findings of the case of study.

4.3. *Phase III*

Based on the obtained results, it is intended to propose a structure of conditions and the governance that main business process of construction companies' central office should meet in order to achieve a positive impact on their projects operational performance. Other industries approaches for change management obtained from the literature will be selected and adapted to the studied reality of the construction industry. This structure of conditions and requirements will have to be aligned to the company´s strategy both at the central office and at construction projects.

5. Main research results

This research is in progress, and the main results obtained until now are those related to the literature review and what has been observed on the surface of the case of study, at the phase 1 of the methodology.

In general, the classification of the business processes in the literature don´t distinguishes between operational processes and those business processes at the central office. For example, [18] groups them in 3 sequential types: innovation processes related to the identification of client's necessities and new ways to satisfy them; operational processes; and after-sale processes. A broader classification is made by [4]. They mention a BCIOD+R vision, with processes related to: business, customers, integration, operations, delivery and regulation. Some of them are closer to the central office and others to the projects. Nevertheless, a larger literature review is going to be done in order to identify specific central business processes at the construction industry.

A first approximation has been done to the case of study. Field observations and informal conversations at all levels of the company have been conducted, including central office executives, project managers, crew foremen and workers. As explained by these personnel, central business processes at the following areas are considered as some of the most relevant in terms of their impact on projects´ performance:

- Policies and procedures for worker’s recruitment.
- Equipment management between different projects, including equipment maintenance plans control.
- Supply chain management and inventory policies.
- Contractors’ payment management. Payment systems and incentive policies.
- Quality control and proceedings definition.
- Legal procedures and permissions.
- Knowledge management between the central office and the projects. Timely distribution of working documents and information.
- R&D and new technology incorporation.
- Risk management.
- Safety and accident prevention policies.

Some of them are provoking major project delay and overruns. The most relevant is the recruitment of labor workers. The lack of policies and clear contracting procedures are resulting in staff turnover, constructive errors and a low continuity and pace of work. Another business process carrying some troubles is the equipment management. Repetitive mechanical problems on the equipment that the company owns are delaying the construction operations and increasing the cost, since new equipment has to be rented to external companies.

6. Conclusions

A research effort is carried out currently to understand the link between central business processes of construction companies with the performance of constructions projects. A literature review and a case study have been done, and the next steps of the investigation have been described.

As a first approach to the research topic, the literature review as well as the case of study has shown that there is no much research on the impact of a construction company business processes on the operational performance of its construction projects.

At the case of study first approximation, it can be observed that the lack of clear and systematic central business processes is affecting the performance of the project operations. The most relevant of them are: labor contracting procedures and policies, and equipment management.

The main conclusion is that there is a performance improvement opportunity from the central office processes. The results obtained are important as inputs for the next research steps in order to understand the link between central office and operational processes. This is a work in progress; a deeper view and analysis of the case of study and surveys to other companies has to be done in order to be able to propose an improvement approach aligning the central business process to construction operations. It is expected that research results will be a contribution for those companies that are looking for greater and sustained improvement of the way they carried out their construction work.

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Implementation of Scrum in the Construction Industry

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Abstract

The way in which construction projects are managed has not changed significantly in the last decades; however, stakeholders, materials, competition, and user requirements are continuously changing. This creates a gap between the current managerial view on how construction projects are conducted and how they could be managed to increase efficiency.
The construction industry could use new frameworks for action in the project and product management, and learn from the experiences of other industries. With this background in mind, some construction companies are enhancing the performance of their project teams to improve their competitiveness and increase the added value to their clients and themselves.
This paper investigates the implementation of a framework from the IT sector into the construction industry: Scrum. Conducting a case study, the implementation and application of Scrum was analysed through the evaluation of its different artifacts. This research covers the following questions: Can Scrum be implemented in the design phase of construction industry? What adaptations are needed to use Scrum to improve the design phase of construction projects? How and where could Scrum, or parts of it, be used by the design and planning departments of construction companies?
The results from this study show that Scrum has great potential in the design and planning departments of construction firms. From the analysis of the applications of Scrum in the case study, tangible benefits and weaknesses of the implementation, and its different artifacts, were identified. Finally, this paper gives recommendations about the use of Scrum in the design phase and proposes an outlook to implement Scrum in other phases of construction projects.

Keywords: Agile; Design Phase; Process Model; Project Management; Scrum

1. Introduction

In the construction industry, one of the biggest challenges when creating a building is to account for the unforeseeable [1]. In order to reduce the amount of unforeseeable events, project managers typically use templates, checklists and often models with phases, sub-phases and sub-sub-phases, as indicated for example in [2]. This so-called sequential project management approach aims to plan the project in detail and tries to carry it out without any deviation [3]. The creation of this plan often takes up significant resources before the actual construction has even started. In many cases, these processes are so long that by the time the execution phase has started, the plan needs to be revised because of modified project requirements [4]. Constant modifications of the project requirements coupled with occurring problems in defining the original product requirement causes cost overruns and schedule delay and lowers the product quality. As a countermeasure, agile project management was created [1], whereas agility is defined as *"…the ability to both create and respond to change in order to profit in a turbulent business environment"* [5]. Instead of trying to predict unforeseeable risks, one should approach them as opportunities to profit. Therefore, the agile approach is advantageous to the traditional one, as resource consuming detailed planning from the start of the project is avoided. At the same time, decisions are delayed as long as possible [3, 5].

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Scrum is one of many agile project management methods. It was created by Sutherland and Schwaber between 1993 and 1995 [6]. They were heavily influenced by Nonaka's and Takeuschi's (1986) work [7], and strongly influenced the Agile Manifesto [8], which sets twelve principles and four key values for all agile project management methods.

Section 2 explains the basics of Scrum before the case study is then presented in Section 3 and the implementation in Section 4. The results are shown in Section 5 and Section 6 concludes this paper and gives an outlook for additional implementation of Scrum in the construction industry.

2. Scrum – An agile project management method

Scrum is a framework for product development where different processes and techniques can be applied to complex projects. A typical Scrum process is shown in Figure 16. The Scrum framework consists of the Scrum Roles, the Scrum Artifacts and the Scrum Events [9], which are all explained in the following sections.

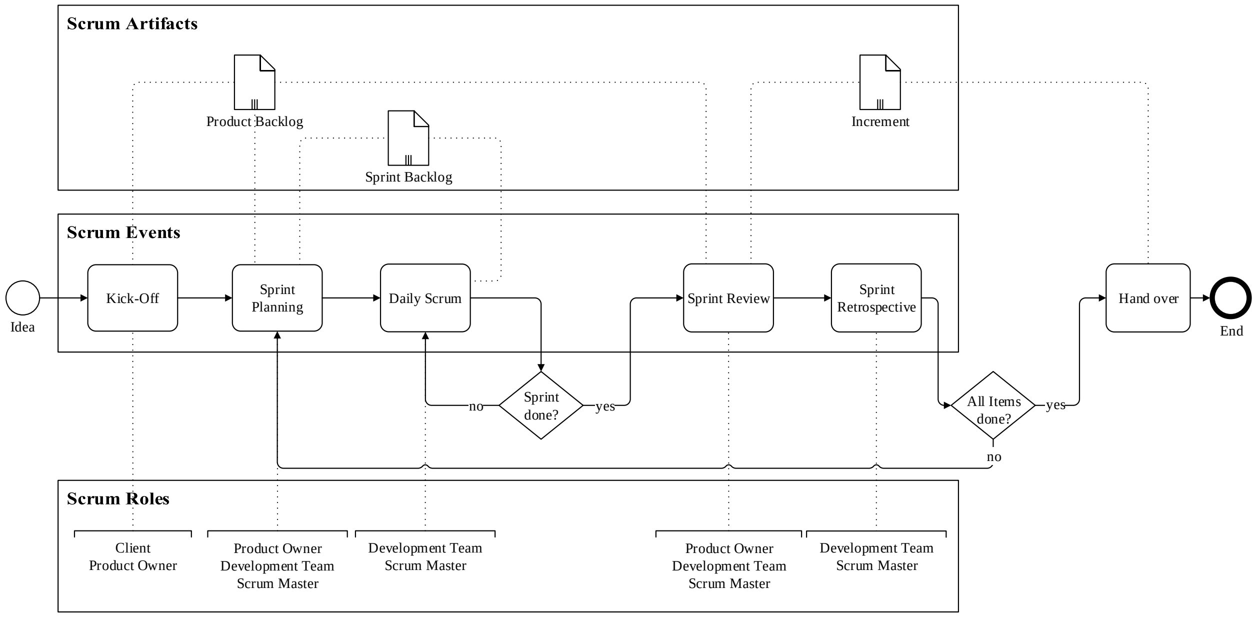

Figure 16: Typical Scrum Process

2.1. *Scrum Roles*

The *Scrum Team* consists of the Product Owner, the Development Team and the Scrum Master. The team is self-organised and cross-functional. All decisions of the project are taken within this entity. All competencies needed for the project are in this entity – there are no advisors to the Scrum Team. The management's sole purpose is to assist and support the Scrum Team to their best so that the Scrum Team achieves its goal.

The *Product Owner* is responsible for maximizing the value of the project and is the sole representation of the client. He is in charge of creating and updating the Product Backlog Items (PBI; Section 2.2) and prioritizes the PBI as well. In addition, the Product Owner also takes into account other stakeholders interests.

The individuals that do the actual work (e.g., design, engineering) are in the *Development Team*. The members of this team are all equal (no project manager) and although each and everyone has their field of expertise, the team is hold accountable as a whole.

The *Scrum Master* ensures that everyone in the Scrum Team understands what is meant by Scrum. The Scrum Master simply enforces the framework given by Scrum and the changes made considering new information. Additionally, the Scrum Master sets all Scrum Events (Section 2.3) and explains to individuals outside the Scrum Team how they can (or cannot) interact with the Scrum Team.

2.2. *Scrum Artifacts*

The Scrum Artifacts can be described as elements with a certain definition in the Scrum framework [6, 9] and are explained in the following: The *Product Backlog* is a prioritised list of different Items (e.g. creating floor plans, defining fire concept, designing load bearing elements). Each Item is divided into Tasks and represents a simple and detailed description of what needs to be done by the Development Team. This list can only be adapted by the Product Owner based on new information regarding the project.

The Product Backlog contains a number of Items, which are selected by the Product Owner and the Development Team. Based on this selection, a list (*Sprint Backlog) is created containing the information* that the Development Team believes can reach the *state of done* during a Sprint (Section 2.3).The entity of the Scrum Team defines a state of *done*. When an Item from the Sprint Backlog is considered as done, it is removed from the Sprint Backlog and is then part of the *Increment*. Therefore, the Increment is the sum of all Items considered done.

To be able to estimate how many Items from the Product Backlog can be worked off within a Sprint, Scrum suggest the use of *Planning Poker*, by which each member of the Development Team receives several cards with the numbers zero, one, two, three, five, eight, thirteen, and so on (Fibonacci sequence). Everyone from the Development Team estimates the amount of work needed for a certain Item so it can be considered done by the end of the upcoming sprint. That includes for example that an architect makes an assumption for the water sewage system even it is not his field of expertise. If the returned card consists of numbers further than three numbers apart in the Fibonacci sequence, the people with the highest and lowest number must explain why they picked their number and the game is repeated until all the cards are within a range of three numbers in the sequence. The average is then used as an estimation of the effort for a given Item [10]. Throughout Scrum the schedules or the amount of work is not calculated with hours, it is done using points. This is done because Sutherland [6] suggests that Gantt-Charts are never accurate and therefore there is no point in trying to assume a number of hours for a task if it does not hold up. For example, these points merely stipulate that an Item with an eight is more work than an Item with a three or five.

2.3. *Scrum Events*

This Section describes the different events in which the Scrum Team can uphold to the key factors of Scrum: Transparency, inspection and adaption [9]. Like in any other project a *Kick-Off* meeting is held – based on the client's demands – and the Product Owner creates the Product Backlog to fulfil this demand.

The *Sprint Planning* has a maximum duration of eight hours for a Sprint of a month (proportionally smaller for a shorter Sprint). During this Sprint Planning the Development Team guesses the amount of work for the most important Items of the Product Backlog with Planning Poker. Following, the Development Team chooses the Items they think can be done in the Sprint, starting with the most important one; this list is called *Sprint Backlog* (see also Section 2.2). While considering all the Items from the Sprint Backlog, a bigger goal – the Sprint goal – must be defined. This enables the Development Team to always ask (inspect) themselves: Is this work I am doing really necessary for this Sprint (goal)?

When the Sprint Planning is done, the Development Team can start working on the Items during the Sprint. The *Sprint* is a fixed timeframe in which the Development Team aims to reach the state of done for each Item. During the Sprint no changes are permitted to the Items, unless the value or the scope of the Items – with consultation of the Product Owner – is increased. By the end of the Sprint the Items that cannot be considered done are moved back to the Product Backlog and will be re-evaluated in the next Sprint Planning.

During the Sprint, the Development Team and the Scrum Master meet daily for the *Daily Scrum*. The Daily Scrum is a 15 minutes meeting scheduled at the same time and same location every day during a sprint. Every member of the Development Team comes prepared to this meeting and answers the following three questions:

- What did I do since the last Daily Scrum to help the Development Team to reach the Sprint Goal?
- What will I do until the next Daily Scrum to help the Development Team to reach the Sprint Goal?
- What are my obstacles that prevents me or the Development Team to reach the Sprint Goal?

The Scrum Master is responsible that during these 15 minutes only these three questions are answered and that the entire Development Team is present. If needed, a follow-up meeting can be set between the involved members. This meeting is also used for inspection: The members of the Development Team are seeing their own progress and everyone knows what the others are working on. Further, through the constant interactions between experts of different areas everyone starts to gain new knowledge outside their expertise.

After each Sprint, the Increment is inspected by the Scrum Team during the *Sprint Review* and if needed adaptions are made to the Product Backlog based on new information. The Sprint Review has a maximum duration of four hours for a one-month Sprint. The following task are addressed during the Sprint Review:

- Product Owner explains what Items reached the state of done and which did not.
- The Development Team discusses what went well during the Sprint, what did not and how the problems where resolved.
- The Development Team presents the Increment and answers questions if needed.
- The Product Owner discusses the Product Backlog and guesses a completion date.

After the Sprint Review the *Sprint Retrospective* meeting is usually held. The goal of this meeting is to discuss involved parties, processes, techniques, relations and how they interacted. Therefore, “what was done?” is not inspected, but “how was it done?”. In doing so, the Scrum Team can suggest improvements to the process and gradually improve their performance.

3. Case Study

Scrum was implemented in the design phase of an ongoing project consisting of three four-story multi-family buildings for the Swiss market with a total floor area of about 2’100 m^2 divided into eleven flats and 200 m^2 of commerce space. Design, engineering and production are done in Tallinn (Estonia) and the prefabricated timber-modules will be transported from Estonia to Switzerland.

The project was planned is accordance to the Swiss Standard SIA 112 [2]. That standard includes six phases to construct a building using the traditional sequential approach:

- Phase 1: Strategic planning
- Phase 2: Preliminary studies
- Phase 3: Project
- Phase 4: Invitation to bid
- Phase 5: Implementation
- Phase 6: Management

Phase 1 was already completed so this case study focused on the implementation of Scrum in Phase 2 and Phase 3. According to [2], Phase 2 starts with the project definition, includes a feasibility study and ends with the selection of the best project to meet the defined requirements. For Phase 3 the first goal is to perform a concept and profitability optimisation, followed by a project and cost optimisation. At the end of Phase 3, everything should be ready for the application of the building permit. Phase 4 to Phase 6 were excluded from this study.

The initial target for this project was to apply for the building permit within a month from the start of Phase 2. After two weeks using Scrum, it was realized that the original goal was not feasible so the timeframe to apply for the building permit was extended to 15 weeks, to ensure that the application would be accepted with the minimum number of imposed building restraints or objections from the building officials. The use of Scrum in the project was followed for a period of eight weeks in 2015, and during that time the authors participated in all Scrum Events. In addition, an interview was conducted with the Development Team and the Scrum Master at the end of the eight weeks.

4. Implementation of Scrum

As Scrum is empirical, it is based on transparency, inspection and adaptation [9]. The general Scrum framework with the multiple events, artifacts and roles (Figure 16) can be adapted to fit the requirements of a project. Although it is recommended to use the framework as a whole – not only parts of it – one may modify Scrum to achieve specific goals. The roles, events, and artifacts used in this case study are summarized in Table 13.

Table 13: Events, artifacts and roles used (✓)

Scrum Team			Scrum Events					Scrum Artifact			
Product Owner	Development Team	Scrum Master	Sprint	Sprint Planning	Daily Scrum	Sprint Review	Sprint Retrospective	Product Backlog	Sprint Backlog	Planning Poker	Increment
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

The Product Backlog was created by an architect from the Development Team and the Scrum Master, instead of the Product Owner. Every member of the Development Team, as well as the Scrum Master, were required to attend all Scrum Events. They were also required to participate in the Scrum Review and Planning with the Product Owner. The use of Planning Poker was not implemented until Sprint number five, and before that the number of Items that could be done in a Sprint was entirely based on the experience from the Development Team.

At first, the Sprint duration was fixed to five working days. This meant that on Monday the Sprint Planning was held, from Tuesday to Thursday work took place and information was exchanged during the Daily Scrum. On Friday, the Sprint Review and Retrospective was conducted. After four weeks, it was found that it was not enough time to address all the Scrum Events and do the required work during the duration of the Sprint. Therefore, the Scrum Team decided to adjust the Sprint duration to two weeks, which allowed for a more realistic timeframe.

5. Results

Every Daily Scrum was recorded and systematically analysed using a template specifically developed for this study with eight questions. Every question was graded by the authors with marks in the range of 1.0 (not measurable) to 6.0 (excellent). The questions answered at the end of each Daily Scrum, along with their absolute weight, are summarized in Table 14.

Table 14: Weight of Daily Scrum questions

Question	Absolute weight [%]
Q1 - How many participants completed a Task?	33.3
Q2 - How many participants answered the three core questions?	33.3
Q3 - How long was the Daily Scrum?	6.6
Q4 - Took the Daily Scrum place at the same location and time as always?	6.6
Q5 - Was someone absent, late or left early?	6.6
Q6 - How many participants talked longer than three minutes?	3.3
Q7 - How many participants talked less than a minute?	3.3
Q8 - How many extern participants talked?	6.6

The weight shown in Table 14 was set to emphasise the core questions (Q1 and Q2). The evaluation of the Daily Scrums is summarized in Figure 17.

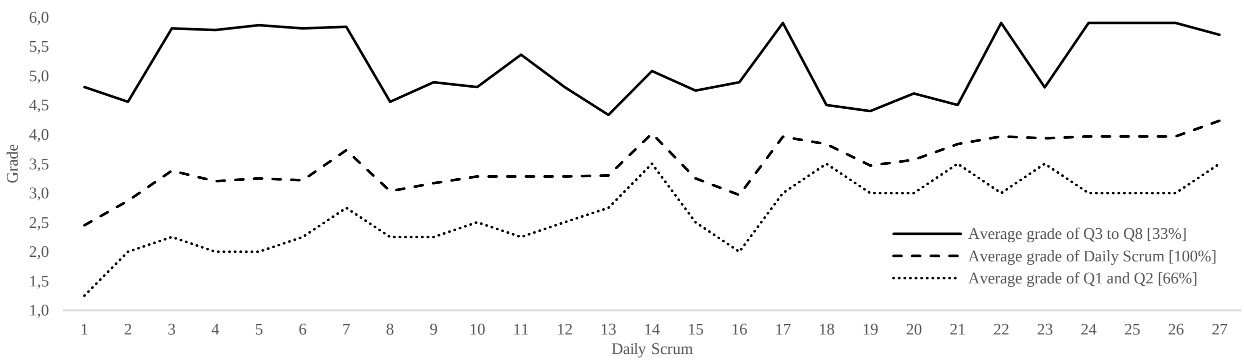

Figure 17: Weighted evaluation of Daily Scrums

The performance of the Daily Scrum, as represented by the average grade, increased from a 2.5 (very poor) to a 4.3 (satisfactory-good) over the 27 observed Daily Scrums. This was attributed mainly to the improvements related to question Q2, as with time the Development Team got much better in getting a clear stating what they had done since the last meeting, what they will be working on next and what the obstacles are/were. Question Q1 received to the end low marks as the Items did not consist of Tasks which could be completed in one or two days' work and therefore no improvement was possible.

Figure 18 shows the number of Items in the Product Backlog from the Kick-Off till Sprint number 5. The increase of Items shows that the goal of the project was not clear at the beginning and new Items were added along the way.

At the end of week eight, an interview was conducted with the Development Team and the Scrum Master (with a total of eight participants) and questions were graded from 1.0 (low) to five (high). The results from those interviews showed that the duration of the Daily Scrum was appropriate, the Sprint Planning and Retrospective were slightly too long, and the Sprint Review was slightly short. In addition, the efficiency of the Scrum Events was rated. The Daily Scrum received a 3.9, the Sprint Planning and Review each a 3.5 and the Sprint Retrospective a 3.0.

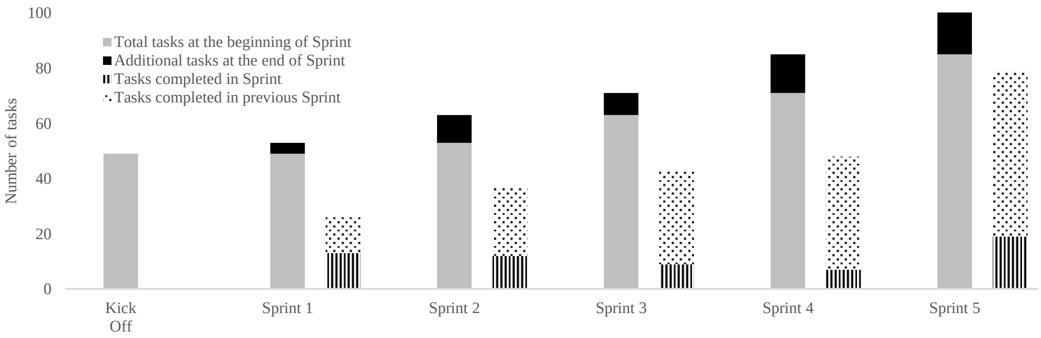

Figure 18: Product Backlog

As the Scrum Framework (Figure 16) states who has to attend the Scrum Events, the attendance necessity was rated by the Development Team and the Scrum Master as well. The grades ranged from 4.0 (Daily Scrum) to a 4.4 (Sprint Review). In addition, the different team members were asked about their view of Scrum regarding the following points:

- Introduction: How was the introduction to Scrum?
- Knowledge: What is your personal state of knowledge about Scrum?
- Necessity: Do you understand why did you use Scrum in this Project?
- Relevance: Do you like the application of Scrum for the Design Process?
- Continuity: Do you know who you can ask if you have questions about Scrum?

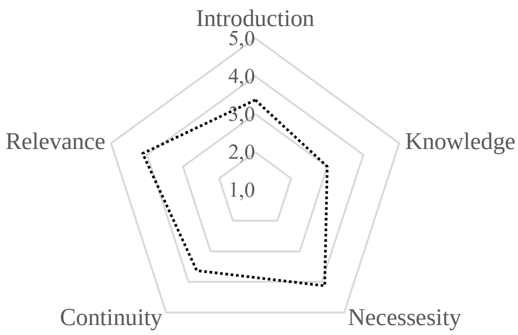

Figure 19: User’s perception about implementation of Scrum with grades ranging from 1 (poor) to 5 (high)

Figure 19 shows that the Introduction and Knowledge about Scrum were low when the project started. It is worth to mention that all eight interviewed participants would like to continue using Scrum in the Design Process instead of the traditional approach they used over years of practice. In fact, after only five weeks of experience, the Development Team was convinced that Scrum was more efficient than their previous approaches and methods. Mentioned benefits of Scrum were a higher transparency, better communication and collaboration, better flow of information and faster project development. Another important advantage was that the many meetings enabled the single member to see the point of view of other team members and starts to understand why something was done in a certain way. Thereby team members improved their knowledge in a field where they were not experts, helping to support the concept of cross-functional teams. The participants also indicated some difficulties when using Scrum, e.g. the missing knowledge at the beginning, no clear project leadership and that a lot of time was needed for voting in the Development Team as the team was hold accountable.

Overall, the disadvantages can be addressed to the low knowledge about Scrum at the beginning of the process; responsibilities and duties of each member were not clear or well defined. Due to this reason, more time was needed for the meetings and the voting as well as the creation of the Product Backlog. The knowledge gained from this process is very valuable and can be re-used for future projects as the description of the Items remains the same and only the scope and some Tasks needs to be adjusted accordingly.

6. Conclusion and Outlook

As shown in Section 4 and 5, the successful application of Scrum in the construction industry is possible. The paper shows that no significant adjustments are needed to the original Scrum framework given by [9]. The following points should be considered when Scrum is applied in the construction industry:

- Get a good understanding of how Scrum works and get all parties (Development Team, Scrum Master, Product Owner, Stakeholder, Management) involved from the beginning.
- Take enough time to create a clear and comprehensive Product Backlog with Items and Tasks.
- Inspect, update and adapt the Product Backlog Items before every Sprint Planning.
- Use Planning Poker for every Item and do it again if changes are made to the Items.
- Attend all the Scrum Events (even members of the Development Team working part-time on the project).
- Make decisions (the Product Owner) on a timely manner in every Sprint Review to avoid putting the Development Team on hold.

Constant inspection and adaption of a new Scrum process will evolve with time and further support and fasten the Design process. Our recommendation is not to try to plan every detail of Scrum as you are used to do, but to *just do and adapt* as needed.

Scrum, as described in this paper, can easily be applied in companies which have almost all the in-house expertise needed for the construction of a building. With the proper framework Scrum may also work with some external experts. However, this results in a higher effort for communication and therefore slowing down the process and defeating its purpose.

We believe Scrum could be applied in the construction phase with Daily Scrums on-site as a means of communication between the different companies to reduce construction time. For example, Daily Scrum could be beneficial to inform construction companies about the work progress and the daily goal (Sprint) of other construction companies also working on site. In this case no relocating of workers would be needed and the time with no progress could be reduced. We see great potential of the use of Scrum for refurbishments, where a daily update about new information of the existing construction could be easily considered and significantly improve the way projects are managed.

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B Corporations – Hype or Hope?

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Abstract

One of the first legal decisions a business owner has to make is often referred to as "choice of entity". Owners must choose a legal framework for carrying out their business purpose. Traditionally the choice has been limited to sole-proprietorships, partnerships, corporations, limited liability companies, or some hybrid form recognized by local laws. Over the past five years an alternative movement has suggested that the entity structure should be more than a legal entity, it should be a structure that provides benefits to the public, community, owners, employees as well as the clients served. These entities are referred to a B Corps and are a new type of organization that uses the power of business to impact social and environmental problems.
Construction companies increasingly stress their advocacy of and commitment to sustainability. Is this truly a dedication to sustainability, merely a marketing ploy, or maybe fear of not "keeping up" with the competition? If one's definition of sustainability is very narrow, it may mean no more than providing services for clients who request such services. However, if one embraces a more robust definition, sustainability may incorporate ideals promoted by the B corporation movement.
The purpose of this study is to investigate the intricacies of the B corporation movement and identify paths or pitfalls that might exist for companies engaged in areas of general contracting. Is this a lot of "hype" or are there truly benefits to be achieved by all involved with a company organized as a B corporation. This paper provides background information on B corporations and reports on the current status of the B corporate movement. In addition a number of companies involved as B corporations will be interviewed in order to ascertain whether participation as B corporations has a positive impact on their overall profitability.

Keywords: B Corporation; Corporation; Legal Entity; Sustainability

1. Introduction

Benefit Corporations aim to have a positive impact on society and the environment while still remaining economically successful. Certified B Corporations are for-profit companies certified through a third-party rating system as meeting "rigorous standards of social and environmental performance, accountability, and transparency" [1]. The rating system evaluates companies' business practices to identify and grade socially and environmentally positive practices. Currently, there are almost 1,700 Certified B Corporations in the world [1], an increase of approximately 70% since this study was started two years ago. The certification process is operated by the non-profit B Lab and consists of a performance review, a legal review, and the signing of the B Corp Declaration of Interdependence and Term Sheet. The B Corporation movement aims to provide greater economic opportunity, an improvement on environmental issues, and employee satisfaction to the involved companies and their surrounding communities [1].

1.1. *Certification Process*

Files B Lab is the 501(c)3 non-profit that runs the B Corp certification process. B Lab creates the certification standards for Certified B Corporations and administers the certification process as an unbiased third party. B Lab also hosts B Analytics, the benchmarking platform for B Corporations, and promotes pro-B Corp legislation. The various components of B Lab are illustrated in Figure 1. Jay C. Gilbert, Bart Houlahan, and Andrew Kassoy founded B Lab in 2006. B Corporation Certification started in June 2007, quickly gaining traction that December when King Arthur Flour publicized their certification by printing the B Corp logo on 10 million bags of flour.

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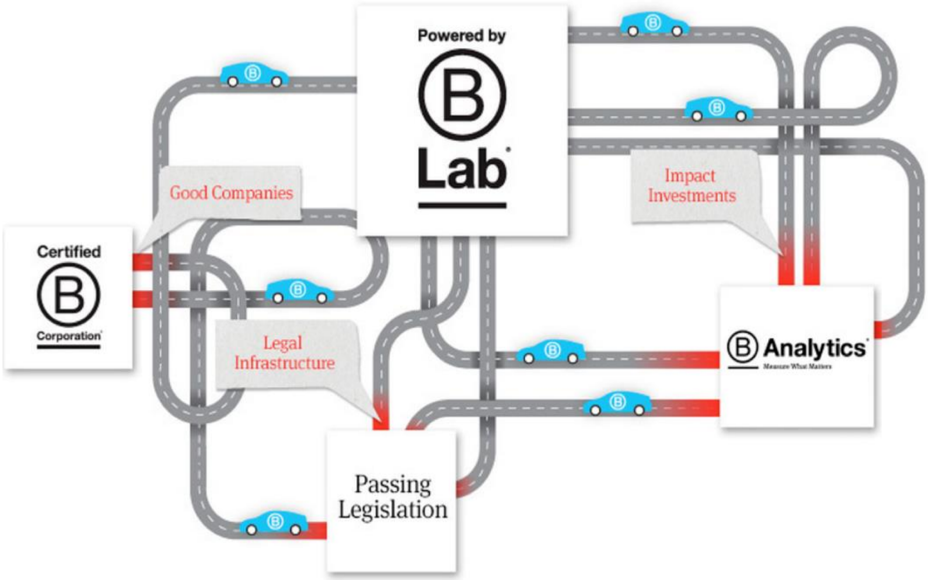

Figure 1 – The B Corporation Roadmap [1]

The first step to becoming a Certified B Corporation is to pass the Performance Requirement. The company undergoing certification must take the B Impact Assessment and receive a passing grade of 80 or above. The B Impact Assessment analyzes the company's impact on its stakeholders, with the analysis varying according to the company's size, sector, and location. The Assessment includes over 350 social and environmental "best practices" that are divided into four categories with differing weights. The first category "Environment" is dived into six subcategories focused on resource use, waste creation, and other various environmental practices. The second category "Workers" looks at the company's social initiatives for its workers; the subcategories include work environment, worker ownership, and compensation, benefits, and training initiatives. "Community is the third category that examines the company's effect on the local community through seven subcategories, such as jobs created, civic engagement and giving, and company diversity. 'Governance" is the final category that evaluates the company's accountability and transparency [1]. The B Corporation website states that completing the Assessment takes 1-3 hours [1].

After the Assessment is completed, the company schedules an Assessment Review with a B Lab Staff member. In the review, the B Lab Staff member helps the company refine their answers for the B Impact Assessment and ensures that specifics of the company are accurately translated into the Assessment. The Assessment Review takes approximately 60-90 minutes [1]. If the company received the 80 or more points required in the B Impact Assessment, the assigned B Lab staff member will demonstrate during the Assessment Review to the company undergoing certification how to submit the necessary supporting documentation. The company will also be required to defend their response to 8-12 affirmatively answered questions on the Assessment. Finally, to complete the Performance Requirement portion of the certification process, the company must complete a disclosure questionnaire listing any sensitive business details for further analysis by the B Lab Staff.

The B Corp certification process also includes specific legal requirements prior to certification completion. The legal requirements were created to support company leaders in their efforts for company growth that benefits all involved stakeholders, as opposed to just corporate shareholders, and to give additional rights to shareholders to ensure that company leaders remain dedicated to B Corp principles. This requirement originated from commentary by corporate leaders that they were forced to abandon the company's ethical principles or socially responsible business practices in favor of maximum monetary reward. An illustrative example is when Ben & Jerry's was purchased by the large multinational corporation Unilever [2]. In fact, the purchase of Ben & Jerry's is considered one of the primary impetuses for the B Corp Movement [3]. By establishing specific socially responsible business practices in the company bylaws, such as support for small-scale suppliers and high worker wages, Ben & Jerry's was able to maintain its dedication to having a positive impact on society and the environment, even after its acquisition by a megacorporation like Unilever.

The legal requirement for B Corp Certification is fulfilled by first altering the company's existing business structure, whether it's a C Corp, S Corp, LLC, or a Sole Proprietorship, to meet the B Corp certification requirements. After certification is achieved, the newly certified B Corp must receive board and shareholder approval and file the company's amended business articles with the appropriate Secretary of State. After the legal requirement is fulfilled, the company undergoing certification completes the process by signing the B Corp Declaration of Interdependence and Term Sheet and paying the annual certification fees. The annual certification fee structure is shown in Table 1 [1].

Table 1: Annual Fee for Certified B Corporations by Annual Sales

Annual Sales	Annual Fee
$0 - $999,999	$500
$1 MM - $4,999,999	$1,000
$5 MM - $9,999,999	$2,500
$10 MM - $19,999,999	$5,000
$20 MM - $49,999,999	$10,000
$50 MM - $99,999,999	$15,000
$100 MM +	$25,000

1.2. *Advantages of Certification*

B Corp Benchmarks is a collection of the results from all Certified B Corporations that completed the B Impact Assessment, aggregated to quantify the companies' successes relative to one another. Data is validated for each participating company through an Assessment Review with a B Lab Staff member, a review of submitted supporting documentation by B Lab Staff, and the completion of a Disclosure Questionnaire by the participating company. Ten percent of all participating companies are randomly selected to undergo an on-site review and recertification is required every two years [1].

One of the primary benefits to becoming a Certified B Corporation is access to the B Corp Benchmarks. The B Corp Benchmarks allow certified companies to compare their own performance with other Certified B Corps. This knowledge promotes business growth and helps to spread the implementation of socially and environmentally positive practices between certified companies [1]. B Lab provides other services and support for Certified B Corps as well, such as with marketing, sales, and fundraising [4]. Once the certification process by B Lab is complete, the B Corp may have access to the B Corp Benchmarks to retrieve data and information on the business practices of other Certified B Corporations. However, until certification is complete, B Lab or any legal ruling does not consider a company a Certified B Corporation. Alternatively, the generic term "benefit corporation" may be applied in certain states to establish a corporate legal status akin to the Certified B Corp label. Benefits corporations must have an established value system similar to Certified B Corporations that commits to social and environmental wellbeing; however, benefit corporations do not have access to B Corp Benchmarks or a working relationship with B Lab. There is also a level of validity given to Certified B Corporations over the generic "benefit corporation" title. While benefit corporations are required to publish an annual report outlining the impact of their social and environmental initiatives, this report is not verified for accuracy by a third party organization, like B Lab for Certified B Corporations [4]. A third party standard of each benefit corporation's choosing must be used to assess every annual report. Standards must be "comprehensive, independent, credible, and transparent". Some suggested standards are Ceres Roadmap to Sustainability, Food Alliance Certified, Global Reporting Initiative, ISO 26000, Sustainability Quotient, and more.

2. Methodology and Data Analysis

The purpose of this study is to examine the B Corporation movement and to ascertain if the movement provides positive results for its advocates, primarily in the construction arena.

The data compiled was analyzed using the qualitative approach of triangulation. The data obtained from the interviews was interpreted using a three-step process. First, the data was analyzed separately according to professional position to ensure that all data has been properly catalogued. Second, the data was compared using the triangulation method, and extensions thereof, to look for commonalities between the various professionals interviewed. The triangulation method is used to integrate data from multiple sources [5]. The goal of triangulation is to find recurring themes that are prevalent throughout the interviews. Extensions of the triangulation method were also used to further develop a rich understanding of dispute resolution. For example, the theory of complementarity was used with the respondents as they were asked questions that are unique, in the sense that they are overlapping as well as different [6]. The goal of using the complementarity approach is to understand the difference in thinking between business owners from different industry sectors. In addition to using the complementarity approach, the researcher used an additional method of triangulation known as expansion [6]. The expansion method was used to extend the range of conceptual understanding by asking questions that target different components of the same framework of questioning.

These methods are of particular importance to this data analysis, since the individuals interviewed were asked a variety of questions. The variety of questioning will ensure that potential biases are reduced, by allowing industry leaders to answer the questions in a manner that corresponds to their professional capacity. Consequently, the triangulation method will serve as a filter, allowing the professionals to provide the reader with a strong interpretation of dispute resolution opinion, relative to their role in commercial construction.

Initially data was coded a priori using themes and keywords derived from the interview questions [7]. The a priori codes were used to label the questions asked. In addition, for analysis purposes, the questions were categorized by which participant was asked the question. The ultimate goal of this research is to provide some indication as to whether the B Corp movement is achieving its intended result.

Questionnaires were sent to all certified B Corporations in the U.S. At the time of this study there were 521 certified B Corporations in the U.S., currently there are 874 [1]. Many responses were received that simply directed the researchers to go to the company web site. These were discounted as non-responsive. Thirty responses were received in which the responders took the time to fully answer the questionnaire.

The first questions asked were used to explore the attitudes of the parties involved with the process. Initially a simple question with an expected outcome was asked and all of the participants agreed that the B Corporation movement was a valuable trait of the company.

Next, the parties were asked more specific questions about how the companies utilized the fact that they were certified B Corporations. These questions inquired about marketing efforts, community relations, employee satisfaction and finally profitability. The ultimate goal was to try and determine if the B Corporate certification had a definable positive impact on the company.

3. Case Study: Rubicon Global

3.1. *Company Description*

Rubicon Global is a waste and recycling solutions provider and a Certified B Corporation. The company is headquartered in Atlanta, Georgia and has about 50,000 sites across North America in all 50 states, Puerto Rico, and Canada. There are eleven primary industries that the company services, and these include: distribution, food service, retail, grocery, hospitality, property management, hospitals, education, government, private equity, and construction. Unlike many waste management companies, Rubicon Global does not own any landfills, haulers, or recycling operations (Rubiconglobal.com); they purely provide management solutions, making them an independent resource for determining optimal, unbiased waste management programs. Their efforts focus on identifying hidden costs associated with waste management needs and streaming administrative requirements. The Rubicon Global website cites a savings of 20% on average for their customers due to a reduction in waste program costs. Cost saving opportunities are found through the use of “innovative technology, industry knowledge, and strategic relationships” [8], with a strong sustainability footing throughout their implemented strategies. The company promotes waste recycling, re-using, or reducing efforts to their customers, in addition to or as part of cost-saving initiatives, and has pledged to divert 100% of their customers’ waste to “truly sustainable alternatives” by 2022 [8].

3.2. *B Impact Report*

A review of Rubicon Global’s 2012 B Impact Report shows an above-average score in three of the four categories. The company received an overall B score of 103, compared to the median of 80 (of all 504 businesses that completed the 2012 B Impact Assessment). They excelled in the Environmental category, receiving 34 points, as compared to the median of 9. For Community, they received 9 points less than the median of 32. For the categories of Workers and Governance, they received 8 and 7 points, respectively, more than the median scores.

3.3. *Rubicon Global for Construction*

The Construction Industry is one of the many industries that Rubicon Global serves. For construction projects, Rubicon Global can provide a waste reduction plan and a cost savings plan, both customized to every individual project. Their services can also be used to help projects attain LEED certification, such as for LEED New Construction’s Materials and Resources Credit 2: Construction Waste Management. Rubicon Global’s construction services focus on specific project types, which include: convenience stores, grocery stores, hotels, office buildings, restaurants, and retail [9].

4. B Corporations for Construction companies

4.1. *Prevalence*

A search for Certified B Corporations with a relation to construction resulted in a list of 49 companies across the globe. This list was further examined to remove search discrepancies. Thirty-five companies are Certified B Corporations that are involved with the building industry. A broad range of business types was included to create a more thorough image of the prevalence of Certified B Corporations within the entire Building (AEC) Industry.

A closer examination of the Certified B Corporation involved with the AEC industry revealed that only five are construction companies, in particular those classified as General Contractors (GCs). A closer look at these companies resulted in additional information on these companies' socially and environmentally positive practices. For environmental benefits, the GCs listed the following initiatives: managing construction waste, minimizing energy consumption, reducing carbon emissions, monitoring indoor air quality, and using materials with low VOCs and low emissive adhesives. For social benefits, the GCs listed the following initiatives: employment opportunities (training and worker development), profit donation, affordable housing, team collaboration, and employee benefits/profit sharing. There were two additional initiatives listed: value engineering for sustainable solutions and general quality management; while these initiatives may have secondary environmentally or socially positive results, their ultimate motive is cost saving, or profit growth.

4.2. *Benefits*

While many construction companies want to promote themselves as sustainable, there are few that have a business infrastructure that is clearly outside the company's sustainability framework and initiatives. A sustainable business is often defined as a company that works towards a triple bottom line, meaning success in the social, environmental, and economic (profit) dimensions [10], as opposed to just profit. By this definition, a B Corp is a sustainable company. By pursuing certification as a B Corporation, construction companies can start the process towards becoming more sustainable. The guidelines established for B Corporations in general provide a clear format for the pathway of construction companies toward sustainability. The certification also provides a marketable and reputable branding mechanism for promoting and defending companies' sustainability efforts.

4.3. *Hindrances*

One hindrance to a construction company becoming a B Corporation is lack of knowledge. Knowledge of the existence of B Corporations is limited across most industries, and this should be rectified with further publicity on the success of Certified B Corporations. There may also be confusion around how to become a B Corporation, since the process is time consuming and can be difficult [11].

Another hindrance to certification as a B Corporation for construction companies is a difficulty changing company values. Larger construction companies may struggle to receive adequate buy-in from company executives to allow for the company value structure to be altered or rewritten. A final hindrance to certification as a B Corporation for construction companies is the restructuring of profit distribution. In order for the necessary programs to be instated, some money may need to be diverted from individuals' paychecks or bonuses to provide adequate funding. There will likely be considerate hesitancy by company executives and employees around this final hindrance.

5. Conclusion

The benefit corporation business structure allows for-profit companies to create and adhere to alternative standards for success. Benefits corporations value their role and impact on society and the environment, in addition to their ability to generate profit, and the benefit corporation status facilitates the communication of and an adherence to these principles. In particular, company leaders of benefit corporations are legally permitted to consider the effect of the business on all involved stakeholder, as opposed to just on company shareholders.

B Lab is a non-profit that administers the Certified B Corporation system. The certification system provides a pre-determined, uniform, and prestigious platform for companies to design and express their entire value system. To become a Certified B Corporation, an extensive series of tests and evaluations must be completed to confirm the company's dedication to environmentally and socially positive initiatives. Once certified, B Corps are added to a web of similarly certified benefit corporations to promote collaboration and growth between and within all involved companies.

The construction industry is a prime industry for certification as a B Corporation because of the industry's desire to express its sustainability and the lack of existing structures to do so. B Corporations are sustainable in the sense that they focus on the continued success of the triple bottom line. By undergoing certification, construction companies can improve their sustainability initiatives and add credibility to their efforts.

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Improvement of Economic Effectiveness of Road Highway Projects

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Abstract

With regards to the strategic role of transport in a country's economic development and the large investments that are required, a thorough economic appraisal of these investments is of high importance. Therefore, it is appropriate to analyze and possibly modify existing methods for evaluating the economic efficiency of road construction at the scientific level, with the support of the real practice experience. Our research concentrates on evaluation of current methods of economic appraisal, their consecutive improvement and on incorporation of the LCCA agenda into the investment decision process. Consequently, it focuses on the possibilities to improve the effectivity of both, an investment decision process and a realization phase through the proposal of very concrete measures based on results of our research and on experience of real practice construction.

Keywords: economic efficiency; investment appraisal; life-cycle costs; HDM-4 software; road transport infrastructure

1. Introduction

This research paper deals with the major deficiencies in the current investment decision process to the highway network and with the major problems and ineffectivities in the consecutive phase of realization. Overall approach of this research paper is to reveal the possibilities to improve effectivity of above mentioned investment decision process and realization phase through proposal of the very concrete measures. In substance it concerns the purposeful synthesis of proper asset management with more effective investment program to achieve higher infrastructure quality. Although this paper depicts the current road infrastructure situation in the Czech Republic, talks about local state offices and agencies and uses local transport infrastructure data, it also analyses global experience and its findings aspire to be of general validity and applicability.

Current importance of this topic is also given due to the currently increasing production of the construction segment and the present situation of financing the construction of roads and highways. In terms of the volume of investments it is favorable mainly due to various European Union's funds (Cohesion Fund and European Regional Development Fund). These funds are primarily to support routes, which should become part of the Trans-European Transport Networks (TEN-T). Czech Republic has committed to complete the TEN-T routes' infrastructure until the year 2030. This is to be carried through the European Union's framework of Transport Operational Programme. This means, that until the year 2030, Czech Republic should almost double the length of its motorway and highway network - from the actual 1242 km to 2180 km. Unfortunately, availability of these European Union's resources in such extent is limited by the year 2023 [1]. To secure sustainability of the development in preset speed of the construction even after this date, when financial resources will rapidly decrease, a significant change in overall approach and resultantly a significant increase in effectiveness is needed. This can be achieved only through increased emphasis on economical, procedural and managerial aspects of both phases of road infrastructure construction - investment decision process and construction realization phase.

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To achieve better understanding of the current practice of appraisal of economic effectiveness of the highway (respectively road) projects, we also analyze one such appraisal – an output of widely used HDM-4 software and the way its results are understood and interpreted.

2. Approach to economic appraisal of the investment

Based not only on vast experience of the American and Czech state highway agencies, main goals and/or areas to be considered during the highway investment's economic effectiveness appraisal are as following:

- transportation system eficiency – improvement of its reliability and efficiency;
- cargo movement and support of economic development - improvement of the road network capacity and regional interconnection;
- traffic safety – goal to significantly reduce human fatalities and injuries due to traffic on all roads;
- traffic congestion reduction - significant reduction of congestion on the road system;
- infrastructure asset development – maintainance, repair and rehabilitation strategy of all roads and structures;
- environmental impacts – To minimize the impact of transportation on nature, environment and population [2,3].

Without proper consideration of all above stated criteria, the investment decision making process cannot be complete.

The current method for evaluating the economic efficiency of road construction is carried out using the methodology of the Czech Road Assessment System (CSHS). For the actual economic assessment, CSHS methodology determines the software tool HDM-4, developed by Birmingham University (United Kingdom), with support from the World Bank [4]. Thanks to its complexity and flexibility to include high number of factors and inputs, this software is used in many European countries [5].

But there is a significant problem to this widely used assessment tool – or actually a problem of this whole assessment approach. It also has to implement data and information that are more of a qualitative and sometime even intangible nature. It is very hard to quantify the value of safety, human life or environmental impact. Of course the tool works mainly with the data of a quantitative kind, more appropriate for economical appraisal. But very often it is that small portion of mentioned soft data that can change the whole result of the analysis and the choice of the accepted variant of the projected investment. The result of the analysis is very sensitive to these data inputs and can be influenced marginally by artificial change in these qualitative indicators. Such a possibility to affect an overall result of the analysis by tweaking mentioned soft data is a major problem itself. An analyst should not have any option to willingly decide over the results of the analysis. Based on the above said, it seems that to achieve a decent level of comparability of individual investment projects, it is necessary to standardize the quantification and financial appraisal of these qualitative/intangible criteria.

3. Assessment tool HDM-4

Software HDM-4 was developed by Birmingham University, with support from the World Bank (WB). Its primary task is to assess the economic efficiency of transport infrastructure projects, but thanks to the comprehensive evaluation it also includes other modules focused on technical aspects of the project. From an economic point of view, the software is based on the principle of comparing zero variant (current status) with new variants, compared by main economic indicators as following:

- Net Present Value (NPV),
- Internal Rate of Return (IRR),
- Benefit-to-Cost Ratio (BCR).

Coming out of these standard and widely recognized indicators, we can compare two or more options among themselves and decide on the most effective solution. Overall assessment of the project is primarily based on the societal benefit [6]. Thus, the actual assessment will also include costs that are not only of the investment and operational nature, i.e. of qualitative/intangible nature as mentioned before, which represents a significant problem regarding their valuation.

From an economic standpoint the most interesting output from HDM-4 is the sum of the project's discounted flows. An example of such an output is shown in the Table 1 below. There are two basic groups of costs. The first group consists of costs associated with the transport route's operation. These are mainly the costs of maintaining the roads, traffic vehicles (fuel, spare parts), accidents (material damage and human injury) and travel time. In the second group there are costs (externalities) related to environmental impacts. These are the costs of air pollution, excessive noise and exhaust fumes (CO_2).

Table 1: HDM-4 output (in millions CZK; source: own research)

	Zero Variant (baseline scenario)						Proposed Variant					
	Costs						Costs					
Year	Manage-ment	Operational	Travel time	Accidents	Externali-ties Total	Total	Manage-ment	Operational	Travel time	Accidents	Externali-ties Total	Total
2016	0,79	19,32	18,26	1,62	7,02	47,01	18,72	19,32	18,26	1,62	7,02	64,94
2017	0,65	18,76	17,53	1,57	6,65	45,16	47,60	18,76	17,53	1,57	6,65	92,11
2018	2,48	18,03	17,22	1,50	6,35	45,58	39,20	18,03	17,22	1,50	6,35	82,30
2019	0,61	17,48	16,65	1,47	6,01	42,22	0,87	17,02	13,06	1,62	2,65	35,22
2046	0,16	5,51	5,36	0,46	1,59	13,08	0,21	5,41	4,20	0,59	0,74	11,15
2047	0,14	5,21	5,15	0,44	1,52	12,46	0,20	5,10	4,01	0,49	0,71	10,51
2048	0,14	4,70	4,89	0,42	1,44	11,59	-6,66	4,59	3,80	0,46	0,69	2,88
Celkem:	**15,28**	**362,36**	**349,88**	**30,78**	**115,56**	**873,86**	**116,27**	**353,67**	**286,66**	**33,85**	**62,05**	**852,50**
Net Present Value		NPV:	**10,90**	Internal Rate of Return			IRR:	**6,10%**	Benefit-Cost Ratio		BCR:	**1,2115**

Table 1 above represents an example comparing the two variants of the project. It compares the baseline scenario, i.e. how the situation was without the projected changes and the proposed variant, which represents an investment opportunity. This project is the construction of 4 km bypass of the village with the necessary anti-noise measures (barrier). Construction costs were roughly determined to CZK 110 million. Other necessary information were obtained using the combination of data from Czech state highway agency (ŘSD), HDM-4 and the Exnad model to calculate the externalities. The project was evaluated for a 30-year period of operation. The main criterion for assessing whether the project is economically viable is an indicator of IRR, which has to reach greater value as the discount rate itself. During evaluation of the project (resp. of the proposed variant), IRR reached the value of 6.1%, while the fixed discount rate was at 5.5%. That made the proposed variant acceptable and meant that it represented savings for the whole society and resulted in the project's implementation. The decisive moments of the overall evaluation of this variant were the total time savings found, the reduction of noise pollution and general environmental impact.

The very tight result also proves above mentioned problem of sensitivity of the qualitative and intangible data valuation with this appraisal approach. Subjective valuation of such inputs represents a serious danger to whole otherwise very sophisticated tool and approach.

4. Life-cycle costs analysis

The life-cycle cost analysis (LCCA) technique is commonly accepted as a useful investment/project evaluation tool. The LCCA now actually makes up one of the most actual topics not only in road constructio. It evaluates the costs associated with the project from its initial preparation until its dissolution. It helps to find the optimal variant of the project throughout its life-cycle. Complex LCCA reflects all the economic variables fundamental to the evaluation - user costs like travel time consumption / delay, safety costs connected with maintenance and rehabilitation projects, agency capital cost, and life-cycle maintenance costs. The need to optimize the cost of construction and operation in the current environment of rising energy prices and the deepening pressure on savings and cost-cutting is increasingly popular. The standard means for determining the LCCA is the Net Present Value (NPV), which represents the present value of future costs incurred during the project's life-cycle; as an optimal variant from the assessed scenarios is that with lowest final present value of future costs. However, there is a problem with selecting an appropriate discount rate. And there are few more technical problems with the LCCA's implementation. Acquiring credible supporting data and information, including the data on traffic or projecting future traffic flows are one of them. Despite such technical difficulties, limited research done and understanding yet achieved of this complex concept, the LCCA has the potential to provide us with valuable data and conclusions.

Figure 1: Life-cycle costs in highway infrastructure construction (source: own research)

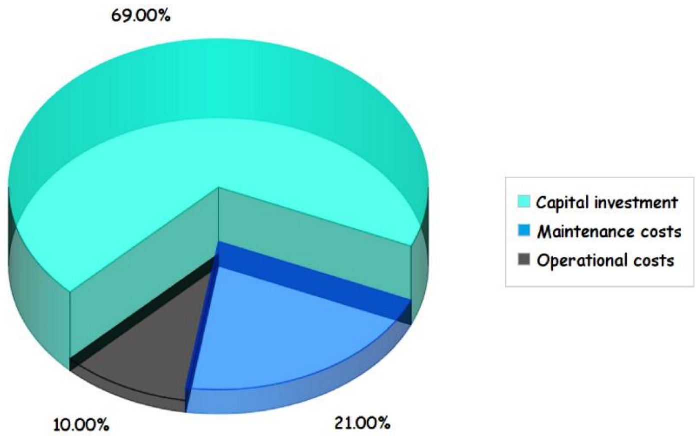

Figure 1 above shows the LCCA of the new motorway sections in the Czech Republic (without the liquidation phase). In the transport infrastructure construction - unlike in conventional building or heavy construction - the largest costs are associated with the investment phase of the life-cycle. The fact that roughly two-thirds of all the costs are connected with the project's capital investment phase gives us a great opportunity to reach significant savings exactly through an increase of effectiveness of the investment decision process and design and construction realization phase.

5. Effectiveness of the realization phase

Disclosing the infrastructure projects' construction business, it is essentially a very attractive business because of the relative ease of achieving extraordinary gains. It derives from the principles of the so-called "measured contract" when the price of the executed work is determined by multiplying the price per unit and the amount actually made of these units [7]. That actually applies to civil engineering in general.

In particular, it is the work not really executed that can be the source of above-average profit. This is the case when reported quantities are larger than actual and where there is an artificial increase in unit prices through change management. For example, a very common situation - the recognition of extraction and transportation of 150 thousand m3 of soil instead of really carried out 100 thousand m3 and not for the contractual unit price per m3, but for the price, increased via change management for inclusion into another class workability (e.g. due different geological conditions).

Such behavior patterns of the suppliers of engineering structures can be quite effectively faced with a combination of these essential measures that we propose and methods and practices, time-proven in the rest of the world:

- Flawless project documentation incorporating maximal standardization of all the project's sections (especially those most costly, when designed and built/produced, i.e. bridges, tunnels and anti-noise barriers). Thorough digital scanning of the terrain and application of Building Information Modeling (BIM) to not to leave much space for any major contract changes during construction. Regular/repetitive frequency of such three-dimensional scanning is also a way to gain an overview and control of really processed quantities (of soil, for example) and a chance to increase fairness of billing with the contractors.
- Correct cost estimate of all individual items (control budget) of the design based on exact bill of quantities prepared by the Highway Agency's own capacities and based on its own cost database (i.e. outsourcing of any of these activities being unacceptable, e.g. using designer's bill of quantities). Consecutive realization phase being in accordance with accepted cost estimate and bill of quantities. Project manager's personal responsibility for these tasks being of crucial importance.
- Evaluating competing bids on the basis of the state agency's own flawless control cost estimate (budget) and rejecting those bids of abnormally low or high values (±10-15% against the control budget). Such approach also eliminates most of the bidders' reasons to appeals against the results of the tender.
- Objective, independent and incorruptible execution of own technical supervision (supervisor / engineer) regarding performed quantities and approved changes to design during the realization phase.
- Confirmation of performed quantities and approved changes to design during the realization phase by an independent authorized subject (quantity surveyor / technical supervisor) beyond commonly used extent. An

additional third-party subject with the lowest possible probability of ties with the contractor is financially favorable especially on larger projects.

- In a sensitive area of environmental protection, clear need for many environmental measures is often a matter of opinion and is hard to determine with certainty. At the same time, such measures are often very money-demanding. To counter above mentioned with financial responsibility and to act in accordance with valid EU's directives, an investor should choose an approach of so called Adaptive Management.
- Applying any environmental protection measures or design variations based on the proportion of probability of a phenomenon and not in a form of precaution, holds a potential for significant savings in comparison to current practice.
- Legal option to foreclose from any further new projects' tenders those contractors, that are in any form of dispute over any past project with the state. Though that this principle has proven its efficiency in various states Europe, it is still not being implemented into the legal codes for public contracts of most of the states. When implemented and practiced, it significantly improves bargaining position of the state. It also fundamentally regulates the behavior of contractors towards the state agencies, bringing it closer to the standards of behavior / relationships of the owner-contractor in the private sector.

6. Summary and conclusions

There are significant inefficiencies in the current decision process regarding investments to the road network. There are different methodologies on investment decision process (based on a location) but for the actual economic assessment of the project, it is the software tool HDM-4, which is most widely used. Thanks to its complexity and flexibility to include high number of factors and inputs we have found this tool as suitable and verified that in a case study. However, main deficiency found was not found to the software but to the general approach to the assessment within every investment unit (i.e. resort or a country). Main inconsistency is in the various type of data that have to be processed. Both, standard technical and financial data and at the same time information that are of a qualitative and intangible nature have to be included into the decision process. Though technically possible, diferrent results based on the latitude of input data values are the problem. This is due to inconsistency in the valuation of those qualitative/intangible data. It is only proper and consistent unification of this valuation for all the projects assessed within every investment unit/area/country, that can improve inter-comparability and quality of the resulting investment decision. Based on the above said, it is evident that to achieve a decent level of comparability of individual investment projects, it is necessary to standardize the quantification and financial appraisal of these qualitative/intangible criteria.

Further analysing the structure of the life-cycle costs in highway construction projects, we affirmed that complex life-cycle cost analysis technique has the potential to provide us with valuable data and conclusions. The fact that roughly two-thirds of all the costs are connected with the project's capital investment phase evidently represents a great opportunity to reach significant savings through an increase of effectiveness of the investment decision process and design and construction realization phase.

Regarding above mentioned phase of realisation of the road infrastructure investment project we targeted major problems and ineffectivities. Based on the practice of project management in this type of projects we summarized the areas, that lead to economical inefficiency most often. We proposed a set of essential measures, methods and practices to effectively face them. Those of being highest importance are as following:

- flawless project documentation incorporating maximal standardization, thorough digital scanning of the terrain and application of Building Information Modeling to decrease the amount of major contract changes during construction, to increase control of really processed quantities and to increase fairness of billing;
- investor's own control budget prepared on the basis of his own bill of quantities and cost database, project manager's personal responsibility for the control budget a for the accordance of the consecutive realization phase with it;
- evaluating competing bids on the basis of the investor's own flawless control budget and rejecting those bids of abnormally low or high values by a pre-set strict rule;
- execution of own technical supervision, i.e. none outsourcing being acceptable for this task;
- if needed, employment of additional third-party authorized subject for the higher-level technical supervision;
- applying any environmental protection measures or design variations based on the proportion of probability of a phenomenon and not in a form of precaution;
- legal option to foreclose from any further new projects' tenders those contractors, that are in any form of dispute over any past project with the state to significantly improve bargaining position of the investor and to standardize contractors' behavior towards him.

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A Two-Stage Model to Support Go/No-Go Decision Making in the International Construction Market

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Abstract

In recent years, many construction companies have attempted to expand their businesses into the overseas market. However, a number of them face difficulties in ensuring that their international construction projects are profitable, mainly because they don’t have an in-depth knowledge of their company’s capabilities and the likely risk level associated with projects. This study proposes a go/no-go decision support model for construction companies. The proposed model simultaneously considers the capabilities of a construction firm, the project risk level, and the firm’s business philosophy or attitude. The creation of the model can be classified into two stages. Stage 1 includes two evaluation models, namely, a corporate competency assessment model and a project risk assessment model. These models are created by an artificial neural network (ANN), and the input and target values are derived from a questionnaire. Stage 2 is a fuzzy inference model whose aim is to support go/no-go decision making. These models have two linguistic input values; one is a net competency value derived from risk score and competency factors, and the other is the company’s business philosophy, which indicates corporate management tendencies. It is expected that the proposed decision support model will support companies in identifying strategies that will facilitate project customization and profit objectives by utilizing the company’s qualified capabilities, complying with their business philosophies, and outlining their risk factors.

Keywords: Fuzzy logic; artificial neural network; risk factors; competency factors.

1. Introduction

1.1. *Research Background*

In recent years, many construction companies have expanded their business activities into the international market. However, a number of them face difficulties in terms of being profitable in the international construction market, largely due to market uncertainty and risk. This has led several construction companies to start analyzing international construction risk and their company’s capabilities in order to facilitate more effective decision making. However, the standard decision-making processes do not accurately reflect companies’ capabilities and the level of risk they face. To address this issue, the current study proposes a go/no-go decision support model that considers the capabilities of a construction firm, the level of risk associated with its projects, and the company business philosophy. This model is created with the help of artificial neural networks and fuzzy logic.

There is currently considerable progress in the construction industry regarding the implementation of construction management strategies using fuzzy logic and neural networks. Specifically, the duration of construction in overseas projects is measured using a fuzzy set theory [1], and fuzzy logic is used to evaluate the rate of cost overrun risk [2]. Based on a genetic algorithm, construction times and costs are traded off to ascertain the optimal trade-off point using the fuzzy set theory[3], and the prediction of financial contingency is progressed by means of artificial neural networks [4].

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While neural networks and fuzzy logic are applicable to many areas of construction, they have been used widely in many other industries. In the case of international construction in particular, companies must assess risk and capability in the engineering phase before the project commences. In essence, any decision models defined based on fuzzy logic and ANNs should be able to predict project go/no-go opinions. Therefore, the proposed model is expected to identify strategies that will meet profit targets based on a company's qualified capabilities and possible risk factors, as well as its business philosophy.

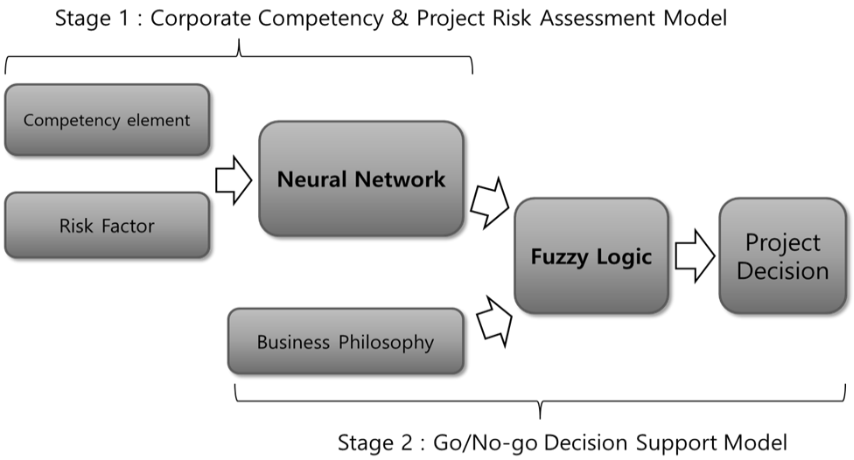
1.2. *Research Framework*

In general, the decision model will support go/no-go decision making in accordance with the attitude of the company in relation to its competence and the risk attached to the project. The model incorporates two stages, as shown Figure 1.

Stage 1 comprises two neural network (NN) models, namely, a corporate competency assessment model and a project risk assessment model. The competency assessment model quantifies the ability of the company by evaluating eight competency factors. The project risk assessment model is developed in the same way and can quantify the project's total risk by evaluating twelve risk factors. These two models are developed using a neural network.

Stage 2 is a fuzzy inference model that supports go/no-go decision making by considering the attitude of the company. This model is created by fuzzy logic using two input values. One is the net competency value that differentiates between corporate competency and project risk, both of which are evaluated in Stage 1 based on linguistic values. The other is the attitude of the company (business philosophy), which consists of five linguistic values: very stable, stable, normal, challenge, very challenge.

Figure 1. Two-stage of the decision support model



2. Research Methodology

2.1. *Artificial Neural Network Model*

Artificial neural networks (ANNs) are a series of machine learning models that were inspired by biological neural networks [5]. They are used to approximate algorithms that can be made using a number of inputs. Typically, an ANN is a system of interconnected "neurons" (nodes) between which information is exchanged. These connections have numeric weights that can be trained based on experience (data).

For our model, the corporate competency assessment model and the project risk assessment model were created using ANNs. Since the models' input consists of a large number of indicators (eight competency factors and twelve risk factors) and it is hard to ascertain the relationship between indicators and target values (one is the company's capability and the other is the project total risk), an artificial neural network was used.

2.2. *Fuzzy Inference System*

In effect, fuzzy logic reduces the ambiguity and uncertainty of human judgment. It is essentially a form of many-valued logic, in which the values of variables may be any real number between 0 and 1. Fuzzy logic can deal with the concept of partial truth, where the truth value ranges between true and false [6]. It is applied in many areas, such as vehicles, electronics, and computers, but is particularly convenient for the construction industry in terms of managing costs and schedules [1, 3, 4, 7].

In stage 2, the go/no-go decision model is created using a fuzzy inference system. This model uses two inputs, one of which is the attitude of company. Since company attitude is hard to quantify exactly, it can be seen as a form of linguistic variable. This is why a fuzzy inference system is appropriate for designing the model.

3. Stage 1: Corporate Competency and Project Risk Assessment Model

3.1. *Corporate Competency Model*

The competency assessment model quantifies the ability of the company by evaluating eight competency categories comprising 27 indicators. These indicators were derived from literature reviews and interviews with experts.

Using the 27 indicators, a questionnaire was developed to ascertain the evaluations for each indicator and the level of competitiveness of the companies. Fifty-nine companies were selected for the questionnaire and these indicators were measured on 5-point Likert scale.

For the corporate competency assessment model, the competency indicators were grouped into eight categories and used to input the data, while corporate competency level was used to target the data.

Table 1: Categories of competency factors

Large categories	Small categories (# of competency indicators)
Construction specialized technical strength	Construction technical strength (2)
	Project management (6)
Overseas project experience	Overseas project performance (2)
	Potential for market growth (5)
Overseas project manpower	International labor transfer and expertise (3)
	Organization growth (3)
Financial stability	Financial stability (3)
	Company sustainability (3)

Based on 59 samples, the corporate competency assessment model was created using Matlab's ANN tool box. Of the 59 samples, 41 (70%) were used for the training model, nine (15%) were used for validation, and nine (15%) were used for testing. This model has two hidden layers and seven hidden nodes. Generally, the number of hidden nodes is decided based on 70%~90% of the number of input nodes [8].

Table 2: Corporate competency assessment model's specification

Set	Number of samples	MSE	R value
Training	41	30.0624	0.9389
Validation	9	41.5291	0.8782
Testing	9	50.2212	0.8432

The output of the corporate competency assessment model represents the level of corporate competency, and the competency score ranges from 0 to 100. A zero score indicates that the company has no overseas business capability or competitiveness

3.2. *Project Risk Assessment Model*

The project risk assessment model quantifies the risk of the project by evaluating 77 risk factors. A survey was conducted to establish the project risk level using 77 factors on a 5-point Likert scale. In the project risk assessment model, the risk factors were grouped into 12 categories and used to input the data, while the project risk level was used to target the data.

Table 3: Categories of risk factors

Large categories	Small categories (# of risk factors)
Host country condition (county level)	Political and administration risk (4)
	Macro-economic risk (5)
Project execution environment (project level)	Owner risk (6)
	Bid and contract risk (12)
	Procurement risk (6)
	Physical risk (4)
	Socio-environmental risk (4)
Project execution capability (corporate level)	Prime contractor risk (9)
	Organization risk (6)
	Construction management risk (11)
	Localization risk (4)
	Construction technical risk (6)

The project risk assessment model is created based on 83 samples. Of the 83 samples, 59 (70%) are used to train the model, 12 (15%) are used for validation, and 12 (15%) are used for testing (Table 4). This model has two hidden layers and 10 hidden nodes (83% of the number of input nodes).

Table 4: Project risk assessment model's specification

Set	Number of samples	MSE	R value
Training	59	111.8594	0.8813
Validation	12	152.8483	0.8214
Testing	12	171.4361	0.7931

The output of the project risk assessment model represents the level of project risk, and the project risk score ranges from 0 to 100. A zero score means that there is no risk attached to the project.

4. Stage 2: Go/No-Go Decision Support Model

4.1. *Fuzzy Input Variable*

The fuzzy input variables comprise two values. One is a net competency value that is calculated as corporate competency scores and project risk scores, which are the results of the stage 1 model. The other value is business philosophy, which indicates the tendencies of corporate management. These two values will be fuzzy input values.

For defuzzification, a centroid method will be used, which usually involves applying a fuzzy frame. The fuzzy inference system type is "mamdani" because the training data set is small, and risk and competency require professional knowledge to make fuzzy rules

4.2. *Net Competency Value*

The net competency value is the difference between corporate competency and project risk score. It is important to note that because these two scores are scaled differently, an indirect comparison is applied; specifically, this is a comparison using sections.

Each input score is divided into five sections, for example, 0–20, 20–40, 40–60, 60–80, and 80–100. Each section is then labeled with numerical numbers from one to five. The net competency value is the difference between the numerical numbers for each section of the input. Thus, the range of net competency values is from -4 to 4, because the maximum value is 5 and the minimum value is 1. Subsequently, the value is categorized into five sections corresponding to different fuzzy numbers (Table 5).

In effect, each section represents five scenarios of net competency. In scenario 1, competency is very high and project risk is very low. In contrast, competency is very low in scenario 5, and project risk is very high. In this study, these five linguistic variables are quantified based on trapezoidal and triangular fuzzy numbers, as shown in Table 5.

Table 5: Categories and fuzzy numbers of the net competency values

Category (linguistic variables)	Net competency value (differences in input variables)	Trapezoidal and triangular fuzzy number
Scenario 1	-4, -3	(0, 0, 10, 30)
Scenario 2	-2, -1	(10, 30, 50)
Scenario 3	0	(30, 50, 70)
Scenario 4	1, 2	(50, 70, 90)
Scenario 5	3, 4	(70, 90, 100, 100)

4.3. *Business Philosophy*

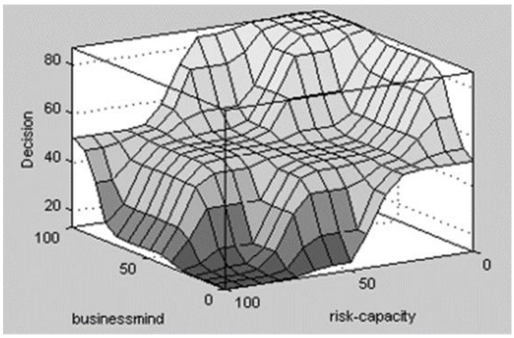
The second fuzzy input variable defines the company's business philosophy. All companies have their own particular management tendencies; for example, some relish the global challenge, others prioritize stable growth, etc. For this reason, business philosophy is defined using linguistic terms such as very stable, stable, normal, challenge, and very challenge. The membership function of business philosophy is the same as that of net competency value.

4.4. *Results of the Fuzzy Inference System*

The fuzzy output variable indicates a project decision consisting of three linguistic terms: no, consider, and go. The membership function is defined using a Gaussian function. Using these input and output variables, IF-Then rules are determined. For example, one of the rules indicates that if the net competency value is scenario 1 and the business philosophy is very stable, then the decision is consider.

Through these fuzzy rules, the go/no-go decision support model's result is as shown below in Figure 2. It can be seen that the decision values are divided into three sections ranging from 13.2 to 86.8, and the three sections represent 13.2 ~ 37.7 / 37.7 ~ 62.3 / 62.3 ~ 86.8. Thus, each range matches the three terms, no, consider, and go.

Figure 2: Fuzzy output surface



5. Conclusion

This study proposes a two-stage model to support go/no-go decision making for construction companies. Stage 1 comprises the creation of two models, namely, a corporate competency assessment model and a project risk assessment model. These models can evaluate company capability and project risk level by using ANNs. Stage 2 is a fuzzy inference model, which can support go/no-go decision making using two linguistic input values; one is a net competency value based on the risk score and competency factors, and the other is business philosophy, which indicates the tendency of corporate management.

However, the study has some limitations. First, the input and target values used in ANN models are based on surveys, so they are unable to produce a fully exact statement on corporate competence and total risk levels. Also, the number of samples here was insufficient to create ANN models. Generally, to establish the net competency value, instead of a direct comparison to identify the differences between corporate competency and project risk scores, an indirect comparison is conducted based on linguistic values.

In further research, input/target values are required that contain not just survey data but also actual numerical data such as profit rate, bid data, and so on. Therefore, the values should be able to explain corporate competence and project risk levels more precisely. Moreover, a more accurate and sophisticated go/no-go decision tool can be developed through a direct correlation analysis of the results of two ANN models.

Acknowledgments

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Identifying Success Factors of Healthcare Facility Construction Projects in Iran

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Abstract

Building of healthcare facilities are considered to be complex owing to uncertainty attached to the nature of these types of projects. Feasibility study through design and construction figured out that many intricate factors should be considered by project managers to make healthcare projects successful. Multiple building components and systems, diverse stakeholders' needs, progressive healthcare technology, specialized functions, different financing methods, and particular building codes and regulation make managing of healthcare facility construction a challenging tasks for project managers. Therefore, understanding the criteria for successful delivery of these types of projects is critical for project managers. Although, evaluating success factors of general construction projects has attracted attentions in recent years, no research has addressed specific nature of healthcare construction projects. This paper aims to identify success factors of healthcare facility projects by interviewing practitioners who have substantial experience in construction of health care facilities in Iran. The qualitative nature of the study gives an opportunity to experts to reveal their insights about projects success factors through open-ended interviews. The result can be used by project managers as a guideline to handle healthcare construction projects successfully

Keywords: Healthcare Facilities, Healthcare Construction Projects, Iran, Success Factors.

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1. Introduction

Construction industry has an important impact on safety, health, environment and society [2]. Success of construction projects have direct effect on mentioned parameters. One of the problems, in project management, is unawareness of success factors which lead to its failure. All projects have been developed for specific purposes so they could be called successful if they are completed in the scheduled time, as well as in accordance with the planned cost and quality. So, there is a need to clearly define success factors in construction projects. After defining these factors, the success rate of projects can be measured. No research was conducted in Iran regarding project success factors. While initially project success is measured based on pre-determined factors, these factors could be different during the size and function of projects. Therefore, knowing factors is the first step to measure project's success. The purpose of this research is to distinguish success factors of healthcare construction projects in Iran. This article tries to find main reasons of success through interviews with managers and civil engineers with at least 15 years of experience in contracting, consulting and employing companies and assessing them.

2. Literature Review

Several researches have been carried out about success of construction projects in different countries specifically in Europe and Eastern Asia. The study on the success factors of construction projects was first done by Rockart in 1982 [10], on the elements which make the real difference between success and failure. Defining success factors of a project is based on it reaching its goals which should be provided for the participants. [11] and [4]. In any project "success" can be announced when it is completed according to the schedule, preplanned budget and needs of stockholders. Project's proper function, profitability for contractors and arising no claims are factors of project success. [1] Which can be divided into two groups: hard, tangible and measurable objectives and soft mental and spiritual and less measurable ones. Time, cost and quality criteria are widely known as the triangle of project management, while safety, environmental health and technical factors are also improving. Client satisfaction, proper communication among the elements of project and absence of dispute are factors that can guarantee a project success. [6]; [3]; [7]. In academic literature client satisfaction is a variable in project success during last decades in and by the time of completing the project evaluating client satisfaction and project success are very close to each other [8].

3. Research Methodology

At the beginning where the existing literature on success factors in projects was studied, the focus was particularly on the resources that identify success factors of health projects in different countries. Review of literature helped this research to recognize factors of project success in other countries. To focus deeply on the subject and identify its hidden angles of this research, qualitative method has been used. This helps the target of this research which is to recognize success factors in healthcare projects. In order to focus on experiences of experts, interviewing has been chosen as the main data collection method. To identify success factors in Iran, 20 interviews have been conducted with experts involved in the construction industry of Iran with at least 15 years of experience. All of the interviewees have the experience in constructing healthcare projects and they have been chosen by Snow ball sampling method. The demographics of the interviewees are shown in appendix 1. Interviews have been conducted in open ended manner so the interviewees feel at ease explaining their points of views. Then the interviews were transcribed. Gathered information regarding the subject is based on valuable experts' experiences. Qualitative analysis was done by coding method. In this method the researcher recognizes the theme by reading the interviews transcription. Gathered information is categorized in this fashion and each group has been integrated which would be discussed in data analysis part.

4. Qualitative Data Analysis

According to the gathered information, success factors in healthcare projects are divided into eight groups which are explained below. It worth mentioning, this information is context dependent and cannot be generalized to wider settings.

Figure 20. Success factors

4.1. *Scope*

Scope includes the processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully. Plan Scope is the process of creating a scope management plan that documents how the project scope will be defined, validated, and controlled. The key benefit of this process is that it provides guidance and direction on how the scope will be managed throughout the project (Project Management Institute (PMI), 2013). All project managers use project scope management throughout the project life cycle to identify and control all aspects involved in a project without a planned scope so practical deliverables are not possible. That is the importance of Scope in Project Management. Based on gathered information, scope management project in healthcare construction projects could be evaluated under two categories of pre-construction studies and feasibility studies. According to O1 one of the biggest owners' problems is not knowing the scopes of projects. Weak pre-construction studies of consulting companies are due to not knowing the details of projects and it has happened many times that there has been no concordance between the culture, climate and the assigned land. C1, C2 and C3 are all expert managers who are aware of the importance of the early studies and they believe that it is one of the reasons of project failure. They all believe that project X (for privacy reasons the real names of the projects are changed) is an obvious example.

4.2. *Time*

Time includes the processes required to manage the timely completion of the project and is one of the most important factors in healthcare projects [9]. Planning, scheduling, political reasons and lengthening of correspondences are four groups of factors that challenges time. N2 believes that project completion is only doable when it is done according to the schedule but N3, N5 and O5 deem precise planning more important than scheduling which is less important. N1 implicitly confirms the above mentioned but believes that accurate determination of priorities and implementation of enforcement activities in more detailed and fragmentary in order to specify prerequisite for any activity are important factors to reach an accurate schedule. But all of the interviewees believe completion of projects in recent years has always been increasing and usually projects face delays. O3, a manager with more than 35 years, emphasizes political reasons increase the time of healthcare project completion and sometimes even suspend them. O6 and C7 mentioned decrease in profitability of projects as the impact of delay in project completion. C6 and C5 mentioned converting old office system to automation to decrease time of correspondences. Although it doesn't seem helping to the reasons of project success, in fact any requests by construction agents are under impact of corresponding time.

4.3. *Cost*

Cost includes the processes involved in planning, estimating, budgeting, financing, funding, managing, and controlling costs so that the project can be completed within the approved budget [9]. Based on gathered information, adding to the above mentioned factors, value engineering is also a parameter in project success. Most of interviewees believe that cost is the most important factor in project success (O4, O8, N3, C7, C2 and C4). O3, with high management and administrative experience in healthcare, projects believe injecting credit to projects is one of the most effective factors in project success. O2 believes the opposite and emphasizes that credit injection without control over the cost not only does not lead to project success but also is one of the factors that challenge it. C5 and C6 approve O2's idea and believe that low but controlled fund has better impact on project success than high and uncontrolled one. C4 mentioned project Y which was completed by value engineering which is an efficient parameter to reach success in projects. O7 confirmed C4's opinion, commenting that using value engineering is not possible in all projects and a deeper look should be taken at the funding but he did not mention a method to replace value engineering.

4.4. *Quality*

Quality includes the processes and activities of the performing organization that determine quality policies, objectives, and responsibilities so that the project will satisfy the needs for which it was undertaken. Quality requires policies and procedures to be implemented within the project's context and the organization's quality management system since, if deemed appropriate, it supports continuous process improvement activities as undertaken on behalf of the performing organization [9]. Quality works to ensure that the project requirements, including product requirements, are met and validated. Based on gathered information, quality as a parameter could be studied under seven groups: (1) Standards compliance, (2) Cost estimation, (3) Proper building methods, (4) Role of sub-contractors, (5) Machinery, (6) Technology, and (7). Quality material. O4 and C7 believe standards compliance satisfies the required quality of projects but C3, O6 and O7 reject this and believe standards compliance just leads to completing the project and does not have any roles in achieving the necessary quality. For reaching proper quality in healthcare projects, proper administrative and materials should be used. O8 with 40 years of experience in this field believes choosing proper minor contractors and up-to-date technology usage are important factors in project implementation. C4 and O1 mentioned the important role of proper cost estimating in reaching high quality and added improper cost estimating would lead to challenges regarding machines usage and the quality of the project is greatly threateneds by wrong choices. O6 while confirming this topic declared by developments in knowledge, technology and variety in software had increased the mistakes in costs estimation in recent years. C2 is a well-known specialist who emphasizes on the quality of the project which has a direct effect on hospital working efficiency and people's health and decrease in quality sometimes leads to doubling the patients' illness. He pointed that in project Z lack of required quality in patients' rooms worsened 5 patients' conditions

4.5. *Human Resource*

Human Resources include the processes that organize, manage, and lead the project team. Project team members may have various skill sets, may be assigned full-time or part-time, and may be added as team members during planning. This adds their expertise to the process and strengthens their commitment to the project. Moral factors, team work and knowledge are three reviewable groups of human resources. The role of human resources is undeniable in the success of a project (C3). Human resources could be parameter of success when they go along order, accuracy, honesty and working consciousness. Doing the work just for the sake of getting it done would not help the project (O7). C5 and N2 while confirming O7's ideas added lack of motivation in human resources of a project is one of the concerns of contracting companies. While confirming previous ideas mentioned project X in which lack of motivation by human resources led to delay. O1 referred to teamwork and its effect on working efficiency, believing wrong and sudden decisions and personal interest of some top executives are strong inhibiting factors for reaching success. C6 rejected this theory and defended high executives and believes administrative health work dominates healthcare projects. C4 and O5 consider using experts as the easiest way for reaching success and believe using inexperienced and irresponsible human resources is a parameter that healthcare projects are facing. O8 agrees with this idea and expresses education is a fundamental and undeniable parameter and believes that using young, educated and well aware of new technologies human resources along experienced ones is a fast way to reach success.

4.6. *Risk*

Risk includes the processes of conducting risk management planning, identification analysis, response planning, and controlling risk on a project. The objectives of project risk are to increase the likelihood and impact of positive events, and decrease the likelihood and impact of negative events in the project. Proper risk management could be one of the factors in success of projects. The importance of project risk management has been needed more and more but activists in construction industry are still facing the problem of risk being unknown and unidentified. Identifying the risks of a project and finding proper solutions could improve the success of the project (N4). C7 agrees with N4 and believes the uncertainty of project could be decreased by ensuring of identification of risk.

4.7. *Environmental*

Since the emergence of human being on Earth, he has dealt with nature and has always tried to control its destruction (N2). Humans have altered the nature along their needs and this alteration went on until the point that humans are the main reason of destruction of the environment. Thus, environmental protection while completing a project has an important role in its success, but unfortunately it has been ignored (O2). O5, by approval of this view, believes that the effects of administrating the projects should be considered in primary studies of project and proper solutions must be offered for these undesirable effects. C1 refers to project X in which improper design of wastewater treatment system of the project cause problems for the region's ecosystem. O7 believes before constructing healthcare projects their adverse effects on the environment should be studied to choose a location with the least harm to the environment.

4.8. *External Matter*

External matter could be studied under three groups: politics, economy and rules and regulations. O8 has a specific emphasis on rules and regulations and their effect on the success of projects and gives several examples during his 40 years of experience in healthcare projects of how violating the rules and regulations led to project's failure. He believes funding problems have always been challenging for the projects in Iran and led to their higher uncertainty. C4 confirms O8 and adds the rules are unanimous in favor of employer being one of the factors of failure. C6 rejects C4 and O8 ideas and speaks of the complete rules and refers to less important role of politics in success of projects. C5 agrees with C6 regarding the complete rules but believes political and economic factors are inseparable from the success of projects.

5. Discussion and Conclusion

Based on conducted analysis it could be said that interviewees are only well aware of the management triangle and believe money is the solution to all the problems. Proper choosing along with knowledge and using young human resources with management knowledge side by side with experienced managers could help the success of the projects. Due to the importance of healthcare projects, this research was conducted with the purpose of identifying factors of success in healthcare projects. To recognize its hidden angles, an interview was conducted with activists in construction industry with at least 15 years of experience. After interviewing 20 of them, the factors of success were divided into 8 themes which were fully explained. It seems that effective people in healthcare projects are either not aware of success factors or lack the knowledge to administer them. One parameter that can be mentioned is absence of a single manager for all the projects. Works in healthcare projects of Iran is in a way that each employer, consultant and contractor have a project manager for the project with different styles of management. Lack of coordination and management knowledge along with weak communication among these managers cause long delays in completion of these kinds of projects or often lead to complete failure. In case that these problems are not solved, decrease in success of projects would be less and less. A certain opinion could only be given, if all the factors of success in projects are considered at the same time

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Appendix 1: The Demographics of the Interviewees

ROW	CODE	ROLE	Education	Field	Experience (year)	Organization Type
1	C1	Project Administrator	Bachelor	Civil Engineer	15	Client
2	C2	Physics	Specialist	Oncology	30	Client
3	C3	Project Manager	Bachelor	Civil Engineer	20	Client
4	C4	Project Manager	Bachelor	Civil Engineer	20	Client
5	C5	CEO	Master	Law	20	Client
6	C6	Project Manager	Master	Civil Engineer	20	Client
7	C7	Project Manager	Bachelor	Civil Engineer	17	Client
8	N1	Project Administrator	Bachelor	Civil Engineer	25	Consultant
9	N2	Project Administrator	Bachelor	Civil Engineer	18	Consultant
10	N3	Project Administrator	Bachelor	Civil Engineer	16	Consultant
11	N4	Project Manager	PhD	Architecture	20	Consultant
12	N5	Project Manager	Bachelor	Civil Engineer	17	Consultant
13	O1	Project Manager	Bachelor	Civil Engineer	25	Contractor
14	O2	CEO	Bachelor	Mechanics	35	Contractor
15	O3	CEO	Bachelor	Mechanics	36	Contractor
16	O4	Project Administrator	Bachelor	Civil Engineer	18	Contractor
17	O5	Project Manager	Bachelor	Management	17	Contractor
18	O6	CEO	Bachelor	Civil Engineer	35	Contractor
19	O7	Project Manager	PhD	Civil Engineer	16	Contractor
20	O8	Project Manager	Master	Civil Engineer	40	Contractor

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Comparing Point-to-point Precedence Relations and Location-based Management System in Last Planner System: A Housing Project of Highly Repetitive Processes Case Study

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Abstract

A comprehensive production system is needed to enhance the flow operations during the works. In this context, the Last Planner System® (LPS) is one of the Lean tools used more often in project management for construction, and in doing so, tries to offset the limitations of the Critical Path Method (CPM). Many tools and techniques have been correctly integrated into the LPS area, some of them required to analyze the task continuity. Over the last years, in the case of housing projects of highly repetitive processes, finding the optimal activity train, hand-offs and milestones using Location-Based Management System (LBMS) was a solution. On the other hand, research about Point-to-point Precedence Relation (PTPPR) exhibited that the main finding is that newly developed point-to-point relations are better from a theoretical and practical point of view than the solutions based on traditional precedence relationships, but they still cannot provide a theoretical perfect solution. The purpose of this paper is to analyze the use of LBMS and PTPPR in housing projects of highly repetitive processes. The research strategy is the case study. Information of a building built in Peru was studied. The first phase is a data collection through direct observation and analysis of documents to describe the work structuring, planning and control. The second phase is the application, analysis and comparison of LBMS and PTPPR. The research method has certain limitations. The results might be biased for the regional behavior of planners. The main outcome of the paper is that it provides pros and cons of both methods.

Keywords: Highly repetitive processes; Housing projects; Last Planner System; Location-Based Management System; Point-to-point Precedence Relations

1. Introduction

1.1. *Last Planner System (LPS)*

According to the Lean Construction Institute (LCI) [1], LPS is a production planning system designed to produce predictable work flow and rapid learning in programming, design, construction and commissioning of projects. LPS has five elements: (1) Master Scheduling: setting milestones and strategy; identification of long lead items, (2) Pull Planning: specify handoffs; identify operational conflicts, (3) Make Work Ready Planning: look ahead planning to ensure that work is made ready for installation; and of re-planning as necessary, (4) Weekly Work Planning: commitments to perform work in a certain manner and a certain sequence, and (5) Learning: measuring percentage of plan completed (PPC), deep dive into reasons for failure, developing and implementing lessons learned.

LPS combines the central elements of task management and flow management for production control in construction, and in doing so effectively combines the control and improvement to fight back against variability and the waste caused by it. However, it is also possible to require increased reliability of deliveries, added conformance to schedule from subcontractors, etc. [2].

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1.2. *CPM Network Method*

Precedence Diagram Method (PDM) has hardly changed during the decades in spite of the critiques it has received about its modeling capabilities. Traditional precedence relations are the subset of the point-to-point relations: in these cases the end points of activities are connected, so they can be called as end point relations [3]. “Conventional managerial methods, like the sequential method of project realization or the CPM network method, deteriorate flows by violating the principles of flow process design and improvement. As a consequence, there is considerable waste in construction. The problems tend to compound and self-perpetuate.” [4]. Construction planning and scheduling methods should explicitly model space as a resource [5].

2. Point-to-point Precedence Relations (PTPPR) and Location-Based Management System (LBMS)

2.1. *Location-Based Management System (LBMS)*

Since Laurie Koskela published his technical report TR72 in 1992, giving rise to the Lean Construction, this trend has evolved [6]. Line-of-Balance (LoB) is a graphic scheduling method which considers location explicitly as a dimension. This allows for easier planning of continuous resource use, which in turn enables cost savings and less scheduling risks as subcontractor’s crews can be kept on site [7]. LoB has been used in Finland since the 1980s in repetitive and non-repetitive construction projects [8]. LBMS is primarily a technical system which optimizes work continuity based on quantity and productivity information and forecasts future performance; it uses flowline, not line-of-balance [8, 9]. LPS and LBMS are complementary [9, 10].

In a building of highly repetitive processes, we bear in mind that this model mimics the execution sequence. However, if we were to make a chart of what was really built on a timeline, we would notice that even in this kind of projects, there can be differences between the flowline planning and the resulting execution curve, as can be seen in Figure 1. Nevertheless, the location units are divided first on stories or basements (level 1), then on daily chunks (level 2), and finally in subsectors or production units that are executed during the workday (level 3), and can be named as the critical path, and therefore, the charts of the highly repetitive buildings tend to look like the one shown on Figure 1.

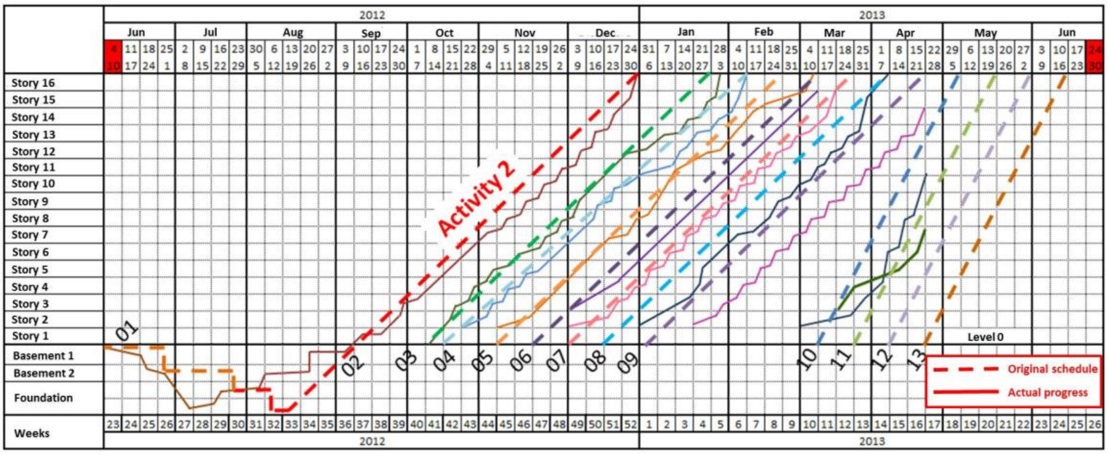

Figure 1: Master Scheduling vs. Actual Progress (Adapted from [11])

2.2. *Point-to-point Precedence Relations (PTPPR)*

Researches about Point-to-point Precedence Relation (PTPPR) showed that the main finding is that newly developed point-to-point relations are better from a theoretical and practical point of view than the solutions based on traditional precedence relationships, but they still cannot provide theoretically perfect solution [3]. According to Hajdu, “fragmenting that is dividing activities into small sub-activities and using FS0 relations between them is also a frequently applied practice. From practical points of view this seems to be the best solution that can be achieved with the existing precedence relations. It can be seen on Fig. 3 that this practice divides the overlapped activities into sub-activities in the necessary number and uses FS0 relations between the corresponding segments” [3].

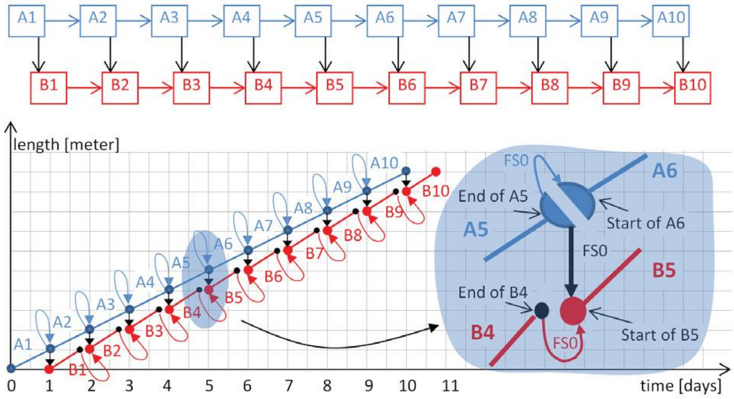

Figure 2: Modeling overlapped activities using fragmentation and FS0 relationships (Fig.3 [3])

“The common characteristic of the point-to-point relations is that any points of the related activities can be connected. Using point-to-point relations the following type of precedence relations can be easily modeled: B can start after the finish of the first 100m of A; the second 100m of B can start as the first 200 m of A has finished etc.; or B can start after the finish of the first day work on A, the second day work on B can start after the finish of the second day work on A, etc.” [3]. Likewise, Professor Hajdu offers a mathematical model and an algorithm for the point to point relations and problem model, and in doing so, compare them with the precedence traditional relations [12, 13]. On the other hand, on projects working under the Lean Construction philosophy, the activity trains (constant production flow) are designed using chunks in which they will be executed daily activities, as shown on the Figure 3. In several cases, these chunks are subdivided in production units that are programmed to be constructed during the workday.

TASKS	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed
	Oct 26	Oct 27	Oct 28	Oct 29	Oct 30	Oct 31	**Nov 1**	Nov 2	Nov 3	Nov 4	Nov 5	Nov 6	Nov 7	**Nov 8**	Nov 9	Nov 10	Nov 11
STRUCTURING PHASE																	
VERTICAL REBAR				S1-P2	S2-P2	S3-P2		S4-P2	S5-P2	S1-P3	S2-P3	S3-P3	S4-P3		S5-P3	S1-P4	S2-P4
VERTICAL PIPING INSTALLATION				S1-P2	S2-P2	S3-P2		S4-P2	S5-P2	S1-P3	S2-P3	S3-P3	S4-P3		S5-P3	S1-P4	S2-P4
VERTICAL ELECTRICAL INSTALLATION				S1-P2	S2-P2	S3-P2		S4-P2	S5-P2	S1-P3	S2-P3	S3-P3	S4-P3		S5-P3	S1-P4	S2-P4
VERTICAL FRAMEWORK	S2-P1	S3-P1	S4-P1	S5-P1	S1-P2	S2-P2		S3-P2	S4-P2	S5-P2	S1-P3	S2-P3	S3-P3		S4-P3	S5-P3	S1-P4
VERTICAL CONCRETE POURING	S2-P1	S3-P1	S4-P1	S5-P1	S1-P2	S2-P2		S3-P2	S4-P2	S5-P2	S1-P3	S2-P3	S3-P3		S4-P3	S5-P3	S1-P4
HORIZONTAL FRAMEWORK	S1-P1	S2-P1	S3-P1	S4-P1	S5-P1	S1-P2		S2-P2	S3-P2	S4-P2	S5-P2	S1-P3	S2-P3		S3-P3	S4-P3	S5-P3
HORIZONTAL REBAR	S1-P1	S2-P1	S3-P1	S4-P1	S5-P1	S1-P2		S2-P2	S3-P2	S4-P2	S5-P2	S1-P3	S2-P3		S3-P3	S4-P3	S5-P3
HORIZONTAL PIPING INSTALLATION		S1-P1	S2-P1	S3-P1	S4-P1	S5-P1		S1-P2	S2-P2	S3-P2	S4-P2	S5-P2	S1-P3		S2-P3	S3-P3	S4-P3
HORIZONTAL ELECTRICAL INSTALLATION		S1-P1	S2-P1	S3-P1	S4-P1	S5-P1		S1-P2	S2-P2	S3-P2	S4-P2	S5-P2	S1-P3		S2-P3	S3-P3	S4-P3
HORIZONTAL CONCRETE POURING			S1-P1	S2-P1	S3-P1	S4-P1		S5-P1	S1-P2	S2-P2	S3-P2	S4-P2	S5-P2		S1-P3	S2-P3	S3-P3

Figure 3: Activity train of the Building structure

The projects’ activity trains carry a great volume of work, with highly repetitive processes and can be divided daily and sequentially, and in doing so, are compatible with the LBMS and PTPPR method. As shown in the example detailed in Figure 2, this practice divides the overlapped activities into sub-activities under the necessary number and uses FS0 relations between the corresponding segments. In this case, because it is so simple, it doesn’t need a mathematical model or an algorithm for its analysis, however for other types of projects, the use of all available tools is recommended, and among them, the mathematical model and algorithm determined by Hajdu.

3. Methodology

The objective of this paper is to analyze the use of LBMS and PTPPR in housing projects of highly repetitive processes. The research strategy is the case study. Information of a building built in Peru is studied. The main result of the paper is that it provides pros and cons of both methods.

3.1. *Case Study*

The case study focuses on a large social housing building. The project consists of twenty eight five-story-buildings occupying 99,330 square meters. Each building includes 100 flats with basic finishing and highly repetitive processes. The structuring phase includes: (1) vertical rebar, (2) vertical piping installation, (3) vertical electrical installation, (4) vertical framework, (5) vertical concrete pouring, (6) horizontal framework, (7) horizontal rebar, (8) horizontal piping installation, (9) horizontal electrical installation, and (10) horizontal concrete pouring. In the finishing phase, the studied activities were: (1) painting, (2) doors, (3) windows, (4) tiling, and (5) flooring.

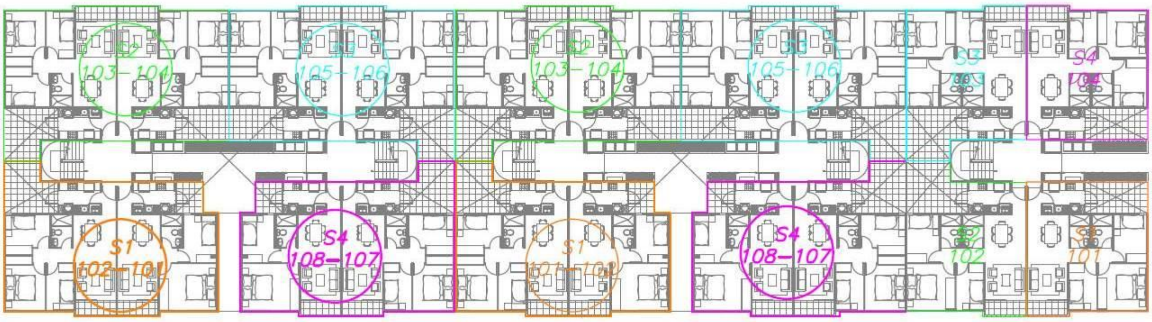

Figure 4: Case study floor plans

The contractor had previous experience in social housing. In the previous project, in the finishing phase, the team faced some constrains in terms of the design and the development of the work structuring. One of the causes of the delaying were the contracts, as the documents only detailed the start and end dates, tolerances and cost. The flow process was not part of the formal agreement with the subcontractors. Ergo, they were reluctant to attend meetings to track their progress, collaborative planning and analysis of underperformance. Based on that experience, this project includes additional management in terms of the contracts, as is to attend the required weekly meetings.

3.2. *Phase 1*

The first phase is a data collection through direct observation and analysis of documents to describe the work structuring, planning and control. In the Peruvian context, in terms of residential buildings, some construction companies implement LPS during the structural phase [14, 15]. However, it is a major challenge to sustain its implementation during the finishing and fit-out phases. Collaborative company can put into practice LPS at an intermediate level, and is still within the learning curve, in a management level as well as a technical level. The results might be biased for the regional behavior of planners. On the other hand, it's important to mention that the degree of industrialization is low, as the structures are made out of reinforced concrete, as due to the fact that ready mixed concrete was hired for the project (and transported by concrete mixing trucks onto the site), the use of prefabricated elements is nonexistent.

3.3. *Phase 2*

The second phase is the application, analysis and comparison of LBMS and PTPPR. For that, the programmed activity trains on the structural or finishing phase, and the actually executed can used in order to generate the LBMS and PTPPR. Windows of time of weeks and days can be used, and level 1 location units (floors), level 2 (sectors) and level 3 (production units).

4. Results and Discussion

4.1. *LBMS and PTPPR*

Figure 5 shows the project's finishing phase planned and executed flowline, and in a similar manner, the project's finishing phase planned and executed Point-to-point relations. It has eleven tasks: (T1) Ceiling and Wall Sealing, (T2) Ceiling and Wall Screeding, (T3) Window Aluminum Frames, (T4) Pane Installation, (T5) Ceiling 1st Coat, (T6) Ceiling 2nd Coat, (T7) Ceiling 3rd Coat, (T8) Quality Control, (T9) Door Frame Installation, (T10) Door Painting 1st Coat, and (T11) Door Painting 2nd Coat.

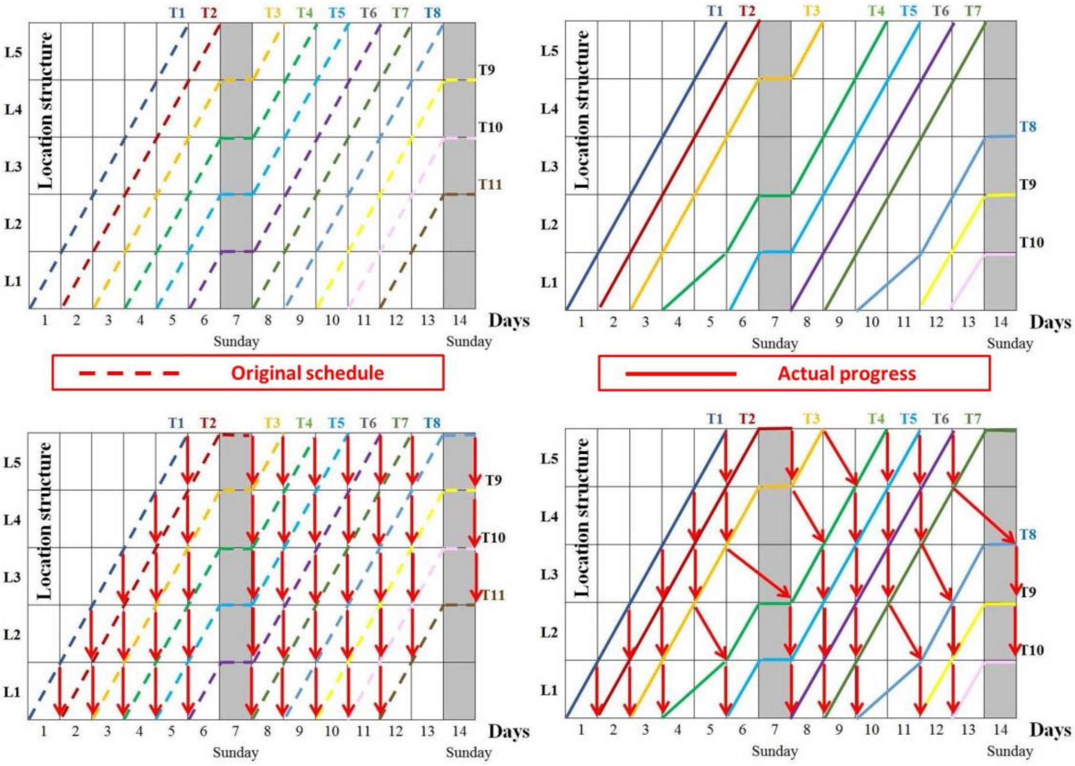

Figure 5: Finishing phase's Flowline and Finishing phase's Point-to-point relations

4.2. *Pros and cons of both methods*

- Flowline is useful to program and globally control building projects when locations area at level 1 (floors and basements) and time is set in weeks, ideal to present reports to the home owners. In this case, PTPPR holds the same amount of information, besides the modeling overlapped activities, which probably holds no interest for the property owners, as shown on Figure 1.
- In programming and controlling the projects when the locations are at level 2 (sectors) and time is set in days, in order to understand the flowline of real execution, one has to be more acquainted with it than with PTPPR. In this last case, the modeling overlapped activities allows us any user to better understand the activity sequence, and visually facilitate the location of the activities that are not executed as programmed, to analyze the root cause of the failure to achieve, as shown on Figures 2 and 5.
- According to Koskela [2]: "planning and controlling production so that the workstations do not starve due to lack of inputs is an inherently difficult task. This is the very reason why tasks and flows have to be considered parallelly in production management: the realization of tasks heavily depends on flows, and the progress of flows in turn is dependent on the realization of tasks." Figure 6 shows the preconditions for the execution of a construction task, like a day's work [2].

A way to deepen the focus of PTPPR probably helps optimize the visual management of the seven resource flows (or conditions) detailed in Figure 6, or of any additional resource flow. The breakdown of the Modeling overlapped activities, as shown on Figure 7, can help with this outcome. Currently, the connecting work is considered.

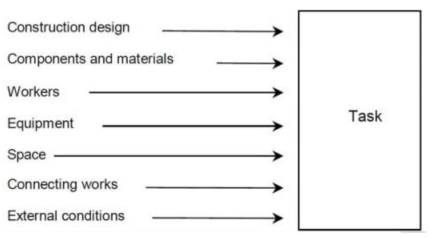

Figure 6: The preconditions for a construction task [2]

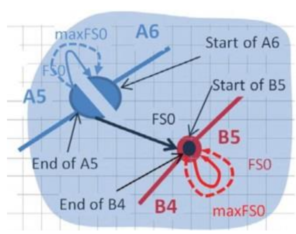

Figure 7: Modeling overlapped activities using fragmentation technique [3]

5. Conclusions

The Critical Path Method system is still very much used in Master Scheduling, and in doing so, originating deficiencies in the Last Planner System implementation. Further study is required in order to connect the planning with the scheduling, and the detailed analysis of systems based on the location units as is the Location-Based Management System (LBMS) or the Point-to-point Precedence Relations (PTPPR). In this analysis, it must be considered (1) the repetitive process level, (2) the analysis time windows, either being monthly, weekly or daily, (3) the location units level, as level 1 (flooring), level 2 (sectors) y level 3 (production units), (4) the number of daily activities in a location unit, (5) the project's industrialization level, among others. Depending on these factors, it can be verified that in highly repetitive projects as the ones studied, the LBMS and the PTPPR can be implemented.

The projects' activity trains carry a great volume of work, with highly repetitive processes and can be divided daily and sequentially are compatible with the LBMS and PTPPR method. The ideas detailed in this article show a clear line of investigation in order to improve the Production Management system of any kind of project, especially in visual management optimization, of all seven resource flows (or conditions).

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Multi-objective Construction Site Layout Planning Using Genetic Algorithms

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Abstract

Efficient layout planning of a construction site is fundamental for successful project undertaking as it enhances both productivity and safety in construction sites. This task usually consists of identifying the temporary facilities needed to support construction operations, determining their size and shape, and optimally positioning them in the unoccupied areas within the site boundaries. The site layout planning problem is a complex combinatorial optimization problem involving multiple objectives and it grows significantly in size as the number of facilities and constraints increases. The existing literature includes a variety of analytical, heuristic, and meta-heuristic techniques for solving the problem but existing studies usually examine a small number of facilities and focus on travel distance minimization, ignoring generally cost related or other decision parameters. The objective of this study is to develop feasible and efficient site layout solutions in a realistic representation scheme taking into consideration not only the total distance traveled but also cost and safety parameters as well. A multi-objective optimization model is developed aiming at minimizing a generalized cost function which results from the construction cost of a facility placed at alternative locations, the transportation cost among locations, and any safety concern in the form of preferred proximity or remoteness of particular facilities to other facilities or work areas. The development integrates the required robust search objective with the optimization capabilities of the genetic algorithms (GAs). The model has been tested on several test cases and the results of a comparative study with existing methods from the literature are presented. The evaluation indicates that the proposed model provides effective and rational solutions, in response to decision parameters and problem constraints, and that it results in more robust layout planning than previous methods both qualitatively and quantitatively.

Keywords: construction site, genetic algorithms, layout planning, optimization, safety

1. Introduction

The formulation of the construction site layout planning (CSLP) problem concerns the placement of a set of facilities in certain locations within the site boundaries, while optimizing layout objectives and satisfying layout constraints. An optimal construction site layout is crucial for project management as it reduces the transportation time and thus the cost of a project and also enhances the productivity and safety of working conditions. The CSLP problem can be defined as a number of predetermined facilities n, optimally being assigned to a number of predetermined unoccupied locations m, where $m \geq n$. The CSLP problem can generally be modeled either as *facility to location assignment* or *facility to site assignment*. The first assigns a set of predefined facilities to a set of predefined locations on site. The method of *facility to site assignment*, on the other hand, assigns a set of predefined facilities to any unoccupied space available on site and results in a more complicated formulation since several spatial constraints must be simultaneously satisfied. Both problem forms can be modeled as *equal-area CSLP* or *unequal-area CSLP* ones depending on whether all facilities can fit to every possible location or not. The CSLP problem can also be distinguished as a *static* or a *dynamic* one depending on whether non-changing or changing site facilities and site spaces are considered in different project phases.

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A variety of methods have been adopted to perform the optimization process, ranging from mathematical models to knowledge-based systems. Algorithms applied to CSLP can be broadly classified into artificial intelligence (AI), evolutionary algorithm (EA) and swarm intelligence (SI) methods. The decision to choose one of these algorithms depends on the solution quality, computational time, interaction of parameters, complexity, and behavior of the algorithm, especially in the analysis of larger problems [1].

Within artificial intelligence techniques, Yeh [2] proposed the use of annealed neural networks, merging the features of simulated annealing (SA) and the Hopfield neural networks (NN). Tam et al. [3] proposed a nonstructural fuzzy decision support system which integrates expert judgment into computer decision modeling.

Evolutionary algorithms are mainly represented by genetic algorithms (GA). Li and Love [4] used GA to solve the site-level facility layout problem while satisfying layout constraints and requirements. The same authors extended the previous model to the unequal–area layout problem ([5]). Mawdesley and Al-Jibouri [6] presented a sequence-based genetic formulation of the CSLP problem and evaluated its performance by comparing results to that of Yeh ([2]). El-Rayes and Khalafallah [7] presented the development of an extended site layout planning model that incorporates a trade-off between safety and cost on site using GAs. Lam et al. [8] introduced a joined max-min ant system (MMAS) and GA model in which the former is used to develop the initial population for the GA application. Cheung et al. [9] described the use of the GA software Evolver to handle a site pre-cast yard layout problem. Liang and Chao [10] proposed a multi-searching tabu search procedure based on efficient diversification and intensification strategies to effectively improve the various arrangements in the facility layout problem. To arrange the pre-cast facilities in the construction site, Wong et al. [11] developed a GA and a mixed integer programming (MIP) model to generate optimal layout solutions. Finally, Gholizadeh et al. [12] implemented a harmony search algorithm as an alternative tool for the solution of the CSLP problem.

The swarm intelligence algorithms mainly include ant colony optimization (ACO) and particle swarm optimization (PSO) algorithms. Lam et al. [13] employed an ACO algorithm to solve the CSLP problem where the proximity of the facilities was calculated through the application of fuzzy reasoning and the entropy technique. Ning et al. [14] used continuous dynamic searching to guide the MMAS algorithm developed in [8] to solve the dynamic CSLP problem under the objectives of minimizing safety concerns and reducing construction cost. Gharaie et al. [15] presented an ACO algorithm to compare the results with the ones in [4] (further discussion in section 3 of the current paper). Calis and Yuksel [16] proposed an ACO algorithm with local analysis (ACO-LA) to improve the quality of the solution. They have also presented an improved ACO algorithm with parametric analysis (ACO-PA) with the potential to assess appropriate parameter values within the predefined parameter range [1]. Zhang and Wang [17] presented a PSO-based methodology to solve the construction site unequal-area problem, formulated as a quadratic assignment problem (QAP). Finally, Lien and Cheng [18] proposed a hybrid swarm algorithm (namely particle-bee algorithm - PBA) that aims to integrate the respective advantages of honey bee and bird swarms.

The literature review indicates that the majority of existing studies focus mostly on the solution method itself rather than on developing a realistic representation of the problem. As a result, they typically analyze the CSLP problem in a rather elementary manner ignoring important parameters (such as layout costs, either transportation or construction ones) or making simplifying assumptions that result in a rather theoretical solution. The present work aims to improve the realistic representation of the problem incorporating cost and safety parameters in the model and to explore the potential impact of these parameters in site layout planning. A secondary objective is to examine whether new developments in optimization models (represented by recent advancements of commercial evolutionary algorithm software) can be more effective in attaining higher accuracy solutions in such problems compared to older methodologies and tools.

2. Proposed model

The problem presented in this study can be modeled as a quadratic assignment problem (QAP) in which equal numbers of facilities and locations exist. If the number of locations exceeds that of facilities, dummy (fictitious) facilities can be added to the model (with zero distances or frequencies to existing real facilities so that they do not affect the layout planning). The optimization model incorporates the following decision parameters which contribute to the total cost to be minimized:

- Frequencies of trips made between pairs of facilities (per day).
- Distances between the predetermined locations (in meters).
- Transportation cost between locations (in cost unit/meter).
- Construction cost facilities at alternative locations (in cost units).

The cost concept is introduced to the optimization process in order to reflect the geography or other particularity of the construction site area. Two types of costs are considered:

- The construction cost represents the required expenditure for placing a facility at a certain location. Small variations (e.g., ±10%) of the normal construction cost may be expected depending on the surface of the chosen location which may require extra work (surface preparation, excavations, and embankments).
- The transportation cost represents the cost of resource movement along facilities and locations. The transportation cost between two facilities can be generally considered constant (as it characterizes the movement of specific resources), however, it can vary depending on the location and path characteristics between the facilities (e.g., inclined terrain, construction site development along a river bank or other traffic-restraining conditions).

Besides pure economic parameters, the decision for facility placement in practice may depend on other criteria as well. One of them is safety which imposes certain facilities to be close to each other and others to be as far away from others as possible (e.g., storeroom of hazardous materials). The safety enhancement goal is facilitated by means of preference in proximity or remoteness between two facilities. For example, the project manager may decide to place the site office or the labor residence facility close to a side gate in order to avoid large interference of the personnel with the main gate, which primarily serves machinery entrance and exit, and also to provide prompt evacuation in case of emergency. Such preferences can be modeled by increasing artificially the frequency or the cost of movements between the chosen facilities.

The fitness of a solution chromosome is assessed by the total cost associated with the above components. The optimization objective is then to minimize the total cost as indicated by the following relationships:

$$MinTC = \sum_{i=1}^{n}\sum_{x=1}^{n}\sum_{j=1}^{n}\delta_{xi} f_{xi} u_{ij} d_{ij} + \sum_{x=1}^{n}\sum_{i=1}^{n}\delta_{xi} c_{xi} \quad (1)$$

subject to

$$\sum_{x=1}^{n}\delta_{xi} = 1, \mathrm{i} = 1, 2, 3, \ldots, \mathrm{n} \quad (2)$$

where TC is the total cost; n is the number of facilities and locations, δ_{xi} is the permutation matrix variable (δ_{xi}=1 if facility x is assigned to location i, δ_{xi}=0 otherwise); f_{ij} is the trip frequency between facilities i and j; d_{ij} is the distance between locations i and j; u_{ij} is the transportation cost between locations i and j; c_{xi} is the construction cost if facility x is placed in location i.

Construction site facilities usually have varying shape and space requirements. Consequently, some locations may not be appropriate to accommodate certain facilities because of their size or other physical constraints (this is known as the unequal-area CSLP problem). The proposed model incorporates this aspect by considering very high construction cost in case that a facility cannot fit to a location. Furthermore, the location of certain facilities, such as the gates to the site, is often crucial for the operability of the construction mechanism in term of access and transport. These facilities are typically set to predefined locations and are not subject to change but still affect the overall layout planning through their interaction with the rest of the facilities. In other cases, certain facilities may be allocated within a subset of the available locations but not everywhere. The model can meet these expectations and provide the best allocation either by introducing constraints which prohibit the placement of certain facilities to unwanted locations or by adjusting artificially the cost of placement in line with the degree of preference or avoidance of certain locations.

The CSLP problem falls within the NP-problems meaning that as the problem size (number of facilities, locations, and constraints) increases, the set of possible solutions grows exponentially. For this reason, a genetic algorithm has been employed for the optimization process. Genetic algorithms represent one of the most popular meta-heuristics that efficiently address hard NP problems because of their ability to escape from local optima during the optimization search. The proposed GA model was implemented through Palisade Evolver software which runs as an add-in of the Microsoft Excel software.

3. Case studies

The goals of this analysis are (a) to compare the proposed formulation and the solving method with existing ones from the literature and (b) to illustrate how the enhanced model with additional parameters and decision modules perform in comparison to simpler ones. Three benchmark case studies were selected from the literature to serve as the model evaluation basis [4, 5, 15]. These studies analyze the CSLP problem employing varying meta-heuristics to obtain the optimal solution. However, all these studies confine their analysis to consider only input regarding frequencies of movement and distances with the fitness function to express the total distance traveled between location pairs. For the comparative analysis of models, therefore, the transportation and construction costs of the proposed model are initially set equal to one and zero respectively. Following, each new parameter is successively added to the model and the results are compared.

The case study project refers to the construction of two buildings. The construction site consists of 11 facilities which are to be assigned to 11 available locations within the construction area (Figure 1). The frequencies of daily trips between facilities are listed in Table 1 while the distances between the available locations are shown in Table 2. The facilities of this case study are:

1. Site office
2. Falsework workshop
3. Labor residence
4. Storeroom 1
5. Storeroom 2
6. Carpentry workshop
7. Reinforcement steel workshop
8. Side gate
9. Electrical, water and other utility control room
10. Concrete batch workshop
11. Main gate

Table 1. Case study trip frequencies between facilities

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	0	5	2	2	1	1	4	1	2	9	1
2	5	0	2	5	1	2	7	8	2	3	8
3	2	2	0	7	4	4	9	4	5	6	5
4	2	5	7	0	8	7	8	1	8	5	1
5	1	1	4	8	0	3	4	1	3	3	6
6	1	2	4	7	3	0	5	8	4	7	5
7	4	7	9	8	4	5	0	7	6	3	2
8	1	8	4	1	1	8	7	0	9	4	8
9	2	2	5	8	3	4	6	9	0	5	3
10	9	3	6	5	3	7	3	4	5	0	5
11	1	8	5	1	6	5	2	8	3	5	0

Table 2. Case study distances between site locations

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	0	15	25	33	40	42	47	55	35	30	20
2	15	0	10	18	25	27	32	42	50	45	35
3	25	10	0	8	15	17	22	32	52	55	45
4	33	18	8	0	7	9	14	24	44	49	53
5	40	25	15	7	0	2	7	17	37	42	52
6	42	27	17	9	2	0	5	15	35	40	50
7	47	32	22	14	7	5	0	10	30	35	40
8	55	42	32	24	17	15	10	0	20	25	35
9	35	50	52	44	37	35	30	20	0	5	15
10	30	45	55	49	42	40	35	25	5	0	10
11	20	35	45	53	52	50	40	35	15	10	0

In accordance to existing case studies from the literature, three test cases are examined with regard to facility placement constraints:

- *Case 1 (C1)*: All locations can accommodate every facility.
- *Case 2 (C2)*: The main gate and the side gate are assigned to locations 10 and 1 respectively.
- *Case 3 (C3)*: In addition to C2, three facilities (# 1, 3, and 10) are too large to fit to locations 7 and 8.

In terms of the proposed method, four versions are developed which differentiate in terms of the parameters that are incorporated in the decision making process:

- *New-1*: The simplest algorithm form with decision parameters the trip frequencies and distances.
- *New-2*: It additionally incorporates the transportation costs.
- *New-3*: It additionally incorporates the facility construction costs.
- *New-4*: It additionally incorporates a safety preference parameter (site office close to the side gate).

The comparison between the proposed model and representative results from the literature for the benchmark case study indicates that the continuing experimentation with evolutionary algorithms over the years is justified by the improvement potential in the optimization results of such problems. In particular, Table 3 summarizes the optimization results of six different solution methods in one or more of the three case scenarios. It can be observed that as solution methods become more rigorous, there appears notable improvement of the results. Further, the proposed model outperforms almost all previous formulations. In comparison to the best known solution from the literature ([1]), the present solution is identical in the C1 and C3 cases and slightly better (both in layout arrangement and in optimization value) in case C2.

Table 3. Result comparison among existing studies and the proposed GA model.

Test case	*GA (1998)*[4]	*GA (2000)* [5]	*ACO (2006)*[15]	*ACO (2010)* [16]	*ACO (2015)* [1]	*New-1 GA* (2016)
C1	-	-	-	-	12,150	12,150
C2	15,090	-	12,546	-	12,578	12,546
C3	-	15,160	-	12,628	12,606	12,606

In terms of facility arrangement as a result of the decision parameters involved, considerable changes are observed among different formulations. Figure 1 illustrates the facility placement resulting from two existing methods and the four new formulations for the C2 case. Aside from the main gate (#11) and side gate (#8), which have been placed in accordance with the constraints by all methods, the arrangement of the other facilities differs considerably, especially among the four versions of the proposed method, indicating that the transportation and construction costs as well as the inclusion of safety concerns influence the optimal layout decisively. The proposed model also presents acceptable flexibility to existing problem constraints and manager preferences. Figure 2 indicates notable differences in facility arrangement following the constraints associated with the three test cases C1, C2, and C3. In all cases, the model provides solutions that satisfy existing constraints, prioritize given preferences and ensure economic efficiency.

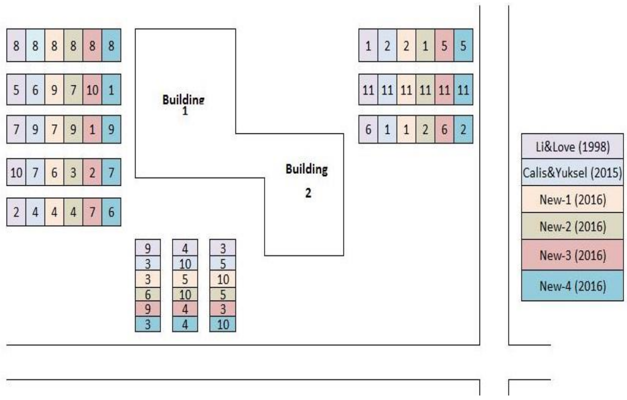

Figure 1. Facility assignment results for test case C2

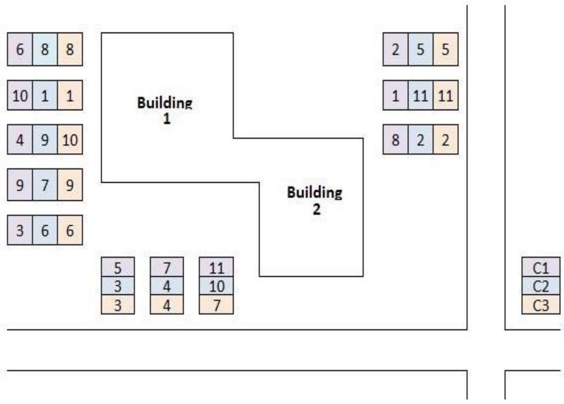

Figure 2. Constraint-driven facility assignment results (New-4)

4. Conclusions

The construction site layout planning (CSLP) optimization problem intends to produce optimal layouts regarding the positioning of temporary project facilities within the construction site boundaries. The problem can realistically be modeled in a multi-objective optimization formulation aiming at minimizing the total traveled distance among facilities and the corresponding transportation cost, the facility construction cost depending on location characteristics, and existing safety concerns resulting from the proximity or remoteness of certain facilities to others. The CSLP problem is among the most challenging ones in project planning process especially as the number of facilities and constraints increases.

In this study, an optimization model is proposed for the unequal-area CSLP problem incorporating transportation and construction costs combined with safety concerns. Several alternative model forms have been analyzed with different mix of decision parameters and constraints in order to investigate the influence of each parameter and constraint. A genetic algorithm has been employed for the optimization as a result of its capability to effectively search within a large set of possible solutions. The proposed model was tested on several test cases and results were compared with previous studies from the literature. The evaluation indicates that the proposed model provides effective and rational layout planning solutions, in response to input parameters and problem constraints, more robust representation of the actual problem structure, and even better performance (in terms of the optimization parameter value) than most existing methods, when compared on the basis of the same decision parameters and model structure.

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Project & Portfolio Management Software Use in Construction Industry

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Abstract

In recent years, a variety of software alternatives and capabilities have been made available for project and portfolio management (PPM). However, very little research has focused on the use of project and portfolio management software in the construction industry. Degree of adoption of PPM software and the reasoning behind these selections may vary among contractors, as each project's unique situation may have an impact on the contractor's decision. The objective of this research is to determine the current trends in PPM software use in the construction industry, and to investigate the reasoning behind the decisions that are related to the PPM software use. A practitioner survey is conducted to reveal the current project and portfolio management software trends of international contractors along with the adaptation of building information modelling in PPM. The questions of the survey are grouped under four sections; project management software practices, portfolio management software practices, evaluation of the PPM software, and BIM use and habits in PPM. The survey findings are presented and discussed to reveal the current trends in project and portfolio management software use within the construction industry.

Keywords: BIM; construction industry, portfolio management, project management, software

1. Introduction

Construction industry is considered as a project-based industry [12]. This notion is based on the fact that every undertaking in construction industry, whether it is a new endeavor or simply maintenance work of an existing enterprise, is a project. Hence, project management plays a critical part in construction industry's fortunes. Not a new term anymore, principles of it have been around for more than 50 years now, project management, is one of the most important methods of management [1]. As Munns and Bjeirmi have concluded in their study, successful project management techniques have a key role to contribute to the achievement of projects" [9]. In today's highly ambitious construction industry where limits of engineering is challenged constantly, successful implementation of project management techniques, and in turn successful management of the project, is crucial and it is ensured by project and multi-project (portfolio) management software packages. As heavy users of project and portfolio management (PPM) software packages, professionals of construction industry differ in their PPM practices and software usage habits. Their projects usually tend to contain greater number of activities compared to other industries but they often include simultaneously on fewer number of projects than professionals of other industries [8]. They also prefer PPM software packages with multiple analysis capabilities like Primavera [8]. Although previous studies have established that project management professionals in construction industry possess a significant interest in improving their project management capabilities [7, 8, 10, 11], examination of available literature does not provide any recently dated study based on professionals' responses. Given the fact that there is now more computing power available recently, the need to update findings of previous studies arises. However, this study does not investigate the differences between project management professionals of different industries as done in previous research. Instead, in this paper, PPM and BIM software usage patterns of project management professionals in construction industry will be identified, addressing current usage patterns, comparing findings to previous studies.

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2. The Study

A practitioner survey, aimed at project management professionals employed by firms listed in Engineering News Record's (ENR) 2015 Top 250 International Contractors list was conducted [4]. The list contains 250 international contractors around the world and members of the list employ hundreds of thousands. The survey is sent to both individuals working at said firms and also firms' general contact email to be filled by their project management personnel. The survey is also sent to projects which are undertaken by joint ventures of multiple ENR Top 250 members. The survey consisted of 47 questions (available upon request), which served to gather information on project management professional's work environment and project management background, PPM software, PPM technique and BIM software usage. The survey was evaluated and pre-tested by several METU faculty members as well as project management individuals from construction industry.

3. Responses

Of the 250 surveys sent, 22 have responded, generating a 9% response rate. While this response rate is slightly lower than the usual 10-20% rate expected for this type of survey [2, 8], when contacted, some of the non-respondents stated that their main reason for not responding was simply lack of time.

4. Results

Findings of the survey are summarized in the discussion below, reinforced by visual breakdown of the results in form of charts and tables. (All graphs and tables are available upon request.) Results are discussed in the procession the questions are asked in the survey; starting with demographic factors (professional background) and work environment of the project management professional, followed by results belonging to how project management, portfolio management and BIM software are utilized. Finally, issues of PPM software according to professionals and areas of future research are discussed.

4.1. *Demographics and Work Environment*

First part of the study portray the work environment of an international contractor. Majority of respondents' firms have a respectable experience and continuity in construction industry with over 70% having more than 20 years of experience in the industry. Data also shows that more than 65% of the respondents work in organizations that employ more than 1000 people, with a significant portion of them (71.43%) working in a project environment and perform project/program management as their primary job function (52.38%). However, individuals whose primary job function can be classified as time management/scheduling/planning also represent a significant portion with 28.57%, which can be attributed to technological advances in special time management positions such as CPM scheduler.

When geographical data is examined, it can be deduced that commercial activities of international contractors are clustered around certain regions regardless of country of origin. Demographic profile of the project management professional in the construction industry shows a significant change when compared to findings of previous research. Respondents with more than 25 years of project management experience has dropped to ~5% compared to over 30% in 2001. However, respondents having experience between experience between 5-15 years have increased significantly, compared to previous studies [8].. This portion translates to the half of all respondents, suggesting increase in computers' role in PM resulted in a more computer proficient generation being employed for PM positions. A large portion of the respondents have received a post graduate degree (75%), which is consistent with the previous studies (74%) [8].

More than half of the respondents (61.90%) spend all or close to all of their time in PM. Of those responded, 38% work on a single project. When compared, those working on a multiple projects are both fewer in their numbers and work on fewer projects per person simultaneously than professionals of other industries. Numbers are also lower than findings of previous research on the subject [8].

4.2. *Project Management Practice and Software Usage Patterns*

During the last two decades, use of PM software steadily increased to a saturation point at the start of the new millennium. Nearly all respondents use or have used or expect to use PM software. Construction industry professionals use PM software for multiple purposes. Majority of the respondents have stated that they use PM software for project planning (scheduling) (90%) and project control (70%). Modern PM Software is also used for features such as general work planning/presentation, resource management and cost management by nearly half of the respondents. Use of PM software have become a project based decision. A decision more often than not made in favor of PM software.

The increased need for PM software use in construction industry is closely related to increased size and complexity of modern projects. A large scale international contractor undertakes projects consisting of 3750 activities on average. Besides project size and complexity, outside requests and software capabilities are the most influential factors affecting use of PM software (Fig. 1).

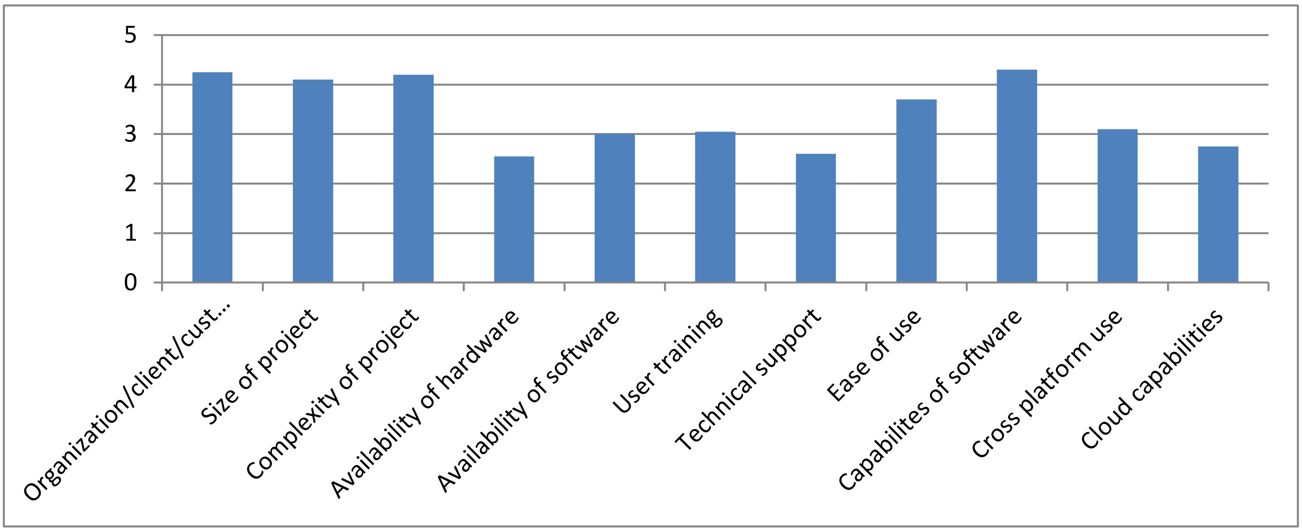

Figure 1: Factors influencing international contractors' decision to use PM software (Average of responses)

As observed in previous studies [8], Primavera Project Planner (P6 and other versions) is still the most popular (44%) with Microsoft's MS Project a distant second (27%) and SAP's different solutions (17%) a distinct third after them. In addition, responses have shown that MS Project is sometimes used together with other PM software, like Primavera, and SAP. As expected and concurrent with existing studies critical path analysis is the most commonly conducted one (90%). Resource loaded schedule analysis (75%) and earned value analysis (55%) are each also performed by more than half of the respondents.

An analysis of the information entered and updated demonstrates that almost every aspect of a project is initially entered to the software, a climb in frequencies compared to previous research. Moreover, every respondent also stated that not all but majority of the data they initially entered is updated. Of the updated data, most frequent are the actual activity start/finish dates and activity durations, once again consistent with previous studies.

4.3. *Portfolio Management Practice and Software Usage Patterns*

Portfolio management is important in means of managing the interdependent projects of a contractor to accomplish strategic objectives in a more efficient way. The idea behind the objectives is provision of optimum risk-return combination. Besides, "fundamental aspect of portfolio theory in construction is the idea that the riskiness inherent in any single project held in portfolio is different from the riskiness of that project held in isolation [6]. Consequently, contractors can have chance to minimize their risks in their expected returns via holding their projects in a portfolio. To figure out the trend in usage of portfolio management of contractors, a section with 10 questions that try to grasp the objectives, practices and contentment is prepared in the survey. Out of 22 respondents, only 1 respondent conducts portfolio management and this indicates a low tendency of conducting portfolio management. When the answers of the portfolio management using respondent are examined, it is seen that the objective includes both minimizing the duration and cost of the project portfolio via using resource and risk management; software of SAP ERP is used; and ETA (Event Tree Analysis) is conducted. Furthermore, even though the majority of the respondents skipped this section of the survey, 80 % of respondents say no to sacrificing some projects by allocating less resource or delaying to meet overall portfolio objective. This may indicate the contractors' general perspective of giving more value to single project management. In the process of investigating the reasons behind this perspective, from face to face interviews with the managers who deal with the projects in Middle East and Eurasia, it is concluded that the scope of project management and control depend upon the requests of specifications owners provide during proposal stage. If the owner does not inquiry any advanced project analysis methods including resource scheduling and leveling analysis, then the contractor firm does not provide a significant resource -such as procurement of PM software for all members in EPC and proposal departments- for project management; and this is generally the case for the contractors who does not respond the section of portfolio management in the survey.

4.4. *Rating and Issues of PPM Software*

To determine the main purpose and context of PPM software usage, 5 different statements including various features of software are given and to be rated from 1 to 10. Weighted averages for corresponding statements are shown in the Table 1 and they declare the context level of the software usage. Accordingly, the quality of the automatic resource scheduling analysis is rated to be the most important one and handling uncertainty and risk capabilities is rated to be least important one. Relatively, weighted average of feature of integration with other software is low, as well. With respect to these results, it can be stated that generally PPM software is not used at a large scale of usage purposes. Furthermore, the importance and level of use of PPM Software change accordingly with the size and complexity of projects so that it is significant to determine to what extend PPM software should be used since not only planning but also controlling of the project is dependent upon this extend. To broaden the use of PM software, managers can be led to go beyond the conventional and limited techniques of planning via endorsing significant improvement in PM software. Correspondingly, the respondents are asked to choose the areas of improvement in software. Most voted one comes out to be better data exchange capabilities with other software (60%), following that optimal resource leveling capabilities (55%) and optimal crashing capabilities (50%) are the most chosen ones. These improvements are all related with the strategic objectives of minimizing the duration and cost of the project. Besides, relatively “enhanced portfolio management” (5%) and “better integration with BIM software” (5%) are rated at a very low percentage which shows that simply managers are not interested in the further improvements in the fields of project management they are not currently using.

Table 15: Rated statements of PPM software features according to their importance

Rated statements from 1-10 (With 1 being extremely unimportant and 10 being extremely important)	Responds (Weighted average)
How do you rate the quality of the automatic resource scheduling analysis of PM software?	7.85
How do you rate the quality of the automatic resource leveling analysis of PM software?	7.25
How do you rate PM software's capabilities to handle uncertainty/risk?	5
How do you rate PM software's integration with other software?	5.45
How do you rate the value of research directed toward improving PM software?	7.40

4.5. *BIM Practice and Software Usage Patterns*

BIM can be defined as tools, processes, and technologies that are facilitated by digital machine-readable documentation which includes information of a building, its performance, its planning, its construction, and its operation [3] BIM is not a single method or software but rather an artificial environment based on smart and detailed models created and updated by multiple parties with multiple software. Compared to PM, BIM is a relatively new concept that still hasn't reached saturation. Even though it has been on an upward trajectory since 2005, BIM adoption levels still cause dispute (Graham, 2016). The most cited resource on BIM adoption levels is a McGraw Hill report that states around 70% of US contractors use BIM (McGraw Hill, 2012), but the report does not state contractors' engagement levels. Respondents of this study however, stated much lower adoption levels with only 20% using BIM actively. Of those using BIM, majority (85%) are using it on either selected projects or sparingly. Decision to use BIM is also dependent on multiple factors. Among those factors, the most influential according to respondents is client/customer requests. Following that are ease of use and software capabilities suggesting that contractors decide to use BIM only when they are convinced that it can be productive enough.

Autodesk products are clear the most frequently used BIM products. Majority (87%) of respondents using BIM, stated that they use at least one Autodesk product (Revit, Navisworks, BIM360 Field etc.) and often more than one (13% use both Autodesk Revit and Navisworks together). Autodesk Revit itself is the single most popular (40%) software while Synchro Professional and Bentley AECOsim Building Designer are the only non-Autodesk software preferred by contractors that responded to the survey.

Despite expectations, most popular feature of BIM used by international contractors is not modelling. While a significant majority (80%) use BIM for 3D modelling, of those respondents using BIM, all stated that they use BIM for clash detection (100%). Third most frequent use (60%) by international contractors are constructability analysis, 4D modelling and cost estimation (Fig. 2).

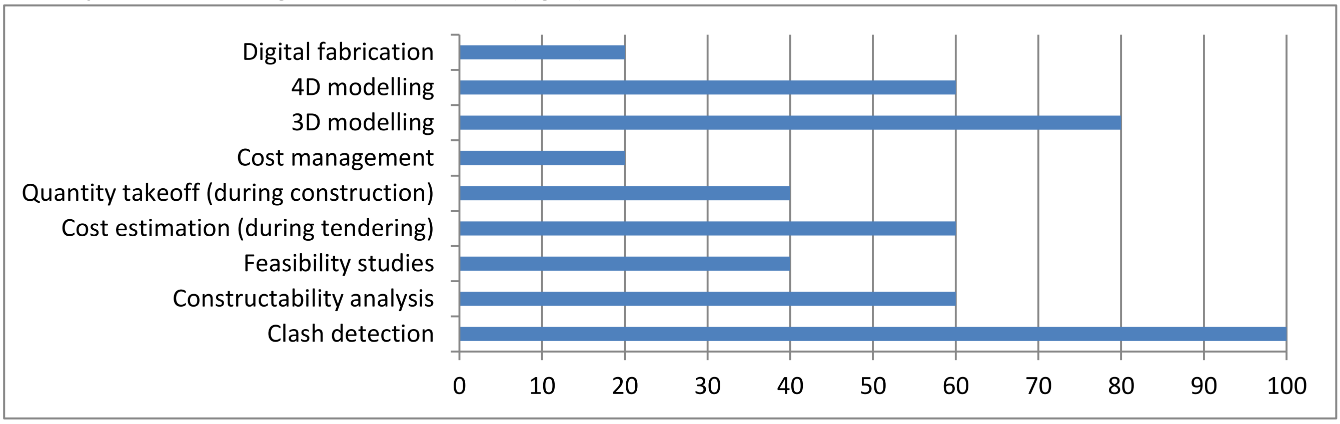

Figure 2: Features of BIM used by international contractors'

5. Summary and Conclusion

The results of this study mainly confirm previous research on the subject that international contractors are heavy users of PM software. The survey respondents tend to work on a few projects at a given time, fewer than previous studies reported, but the respondents projects usually consist of more activities than the other industries,. They also usually work in a project environment and spend a large portion of their time in PM.

The response rate of 9% can suggests that the obtained data may not be representative enough for the entire ENR Top 250 List. While it is true that all respondents are members of the aforementioned list, hence some of world's highest grossing international contracting companies, it can be argued that the available sample is not representative. Even though the study survey was sent out to all members of the ENR Top 250 List, responses were identified to be coming from firms that are familiar with METU. As a result, it can be observed that the responses were concentrated around the Middle East, Eastern Europe, Balkan and Caucasus regions. This fact can be interpreted as majority of respondents are formed by Turkish ENR Top 250 members and ENR Top 250 member firms that are in business with Turkish firms, hence making representativeness of this study questionable. A future study with a greater sample size will yield a more representative sample.

Concurrent with past observations and previous studies, professionals in the construction industry are using PM software quite frequently. Most influential factors on deciding the use PM software are project size and complexity both of which can make the project unmanageable without using any software. Other influential factors are client/customer requests and software capabilities. Construction professionals mainly use the PM software for project planning and control and they use various analyses on their projects, with CPM analysis leading the way.

Research findings suggest that use of portfolio management is not prevalent to the majority of the respondents, since single project management is widely preferred. These results may be due to the small number of respondents and the contractors' market region. Since mainly the respondents are Turkish contractors who take place in ENR Top 250 International Contractors List, they show a similar trend in project management capabilities and habits. Moreover, the results obtained from the survey's section "Rating of PPM Software" are correlated with results in Portfolio Management Practices as giving relatively less importance for uncertainty/risk management capability of software and rating at relatively very low percentage for improvement in portfolio management capabilities of PPM software show that the majority of the respondents are currently not interested in widening the extend of usage of software. Besides, managers seem to be concentrated on the improvement of conventional features such as resource scheduling and resource leveling of PPM software. Consequently, it can be stated that there is a direct correlation between the importance of a feature of software and the need of improvement of similar features.

BIM is often regarded as the future of construction management and the last decade have seen a significant increase in BIM adoption among contractors. However, these high adoption levels seem to be characteristic of all international contractors, as this study's respondents indicate low BIM usage rates. In addition, those who use BIM usually do not use it often. BIM usage is a project based decision, and the clients request is the most influential factor according to respondents. Contractors use BIM for clash detection more than modelling, but both 3D and 4D modelling are also used frequently.

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Construction Materials-based Methodology for Time-Cost-Quality Trade-off Problems

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Abstract

Time, cost, and quality (TCQ) as a triple constraint of construction projects have dependent and conflicting objectives. Considering the limited resources, estimation of the approximate TCQ is a complex and dynamic problem. In addition, the uncertain nature of construction projects and highly variable alternatives make the decision making process a complicated issue. In order to overcome these difficulties, many researchers in the related academic literature introduced different mathematical models on the TCQ trade-off problem so far. In these models, two different approaches were used to estimate TCQ-related data. In the continues approach, it was assumed that the relationship among these three components could be expressed by continuous functions. In the discrete approach, it was accepted that (i) the construction method, (ii) the crew formation, and (iii) the crew overtime policy have some impacts on the project TCQ and that the relationships among these three components become discrete. However, in previous studies, construction materials that have a significant impact on TCQ of construction activities and projects were not taken into account completely during the data formation process. As an exception, El Rayes and Kandil [1] considered different strengths of concrete as material alternatives in a highway construction project. In fact, all the studies focused on proving the applicability of different optimization techniques instead of optimizing TCQ of a real construction project. In this context, some simple projects including a limited number of activities were used to evaluate the applicability of the developed models. Therefore, in the present study, it is aimed to outline a new two-step methodology, including the alternative construction material utilization, for TCQ trade-off problems, especially for building projects which enable the utilization of the high variety of construction materials. For this purpose, the impact of construction materials on TCQ of a project was explained in a detailed manner.

Keywords: Time-cost-quality trade-off, construction material, construction management

1. Introduction

The primary objective of project management is to finish a project within a desired time, cost, and quality. Due to the technological development in today's construction industry, different construction methods, materials, and equipment, which serves to same purposes, can be utilized. During the planning process, by considering these different construction methods, materials and equipment, alternatives are generated, evaluated, and the most suitable one is selected [2, 3]. Thus, the planning process turns to a decision-making process and optimization, which is simply defined as the selection of the best alternative for a given purpose [4], is located in the center of it. Although decisions made in the planning process have a considerable impact on TCQ of a project, they are made with limited information [5]. Therefore, for an effective optimization, all alternatives should be detailed as much as possible. In addition, the uncertain nature of construction projects and highly variable alternatives make the decision making process a complicated issue. In order to overcome these difficulties, many researchers in the related academic literature have introduced different mathematical models on the TCQ trade-off problem by using different optimization techniques so far. However, in previous studies, construction materials that have a significant impact on TCQ of construction activities and projects were not taken into account completely during the data formation process. As an exception, El Rayes and Kandil [1] considered different strengths of concrete as material alternatives in a highway construction project. Therefore, in the present study, it is aimed

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to outline a new two-step methodology, including the alternative construction material utilization, for TCQ trade-off problems, especially for building projects which enable the utilization of the high variety of construction materials.

2. Theorical Background

Components of TCQ as a triple constraint of construction projects are always in interaction with each other. Any changes made in one of these constraints will likely affect the others negatively or positively. Therefore, generating a construction schedule that allows finishing a project within its scope become an important issue in theory and practice. However, the uncertainties caused by the dynamic environment of construction projects and the highly variable alternatives that can be utilized makes the decision making process complicated. In the literature, to facilitate this process, many researchers developed new models by using different optimization tools to analyze the trade-off among TCQ. In this context, by means of Critical Path Method (CPM), researchers generated alternative construction schedules by considering alternative resource utilizations of each construction activity. Since TCQ constraints of each schedule were compromised by means of optimization tools, it is accepted that none of alternatives predominates the other ones.

Numerous researches were conducted on the time-cost optimization of projects since the development of CPM in the late 1950's. The quality concept was first included to the optimization process by Babu and Suresh [6]. In their study, they argued that the quality of a construction project may be affected by crashing the time and accordingly suggested that the quality concept should also be considered during the optimization process.

In construction projects, time and cost are one dimensional concepts. In other words, time and cost can be expressed by a simple value that creates a common perception among project participants. On the other hand, quality has many dimensions and each dimension creates different perceptions among different practitioners. For example, Foster [7] introduced five different views for quality as follows,

1. ***Transcendent view:*** Quality can be perceived intuitively but cannot be expressed easily, such as beauty or love.
2. ***Product-based view:*** The features and attributes of a product define the quality.
3. ***User-based view:*** If the product satisfies users' needs, then it has a good quality.
4. ***Manufacturing-based view:*** If the product matches the design specifications, then it has a high quality.
5. ***Value-based view:*** If the product offers good value for its price, then it has a high quality.

In this regard, all the dimensions of quality should be perceived equally to create a common perception of quality among project participants. Considering above-mentioned quality dimensions, it can be asserted that subjective evaluations come to the forefront for defining the quality. Only product quality is open to objective evaluations as long as it can be expressed by estimative technical features or attributes. Since quality is not a quantitative parameter [8], it cannot be expressed with a simple value like time and cost by nature. Although the difficulty and complexity of calculating the quality was underlined by many researchers [1, 8, 9, 10], quality was digitized in the literature after some assumptions. In this context, researchers in the field of the TCQ trade-off can be categorized under two groups regarding to the relation among TCQ as follows,

1. **Continuous approach:** In this approach, it was argued that the relation among TCQ could be expressed by continuous functions [6, 8, 9, 10, 11, 12]. Here, time was independent whereas cost and quality were dependent variables in the models. Only Ghodsi et.al. [10] suggested that the quality loss caused by crashing the time could be prevented by spending extra money and thus considered the quality as an independent variable. Since quality is correlated only with time and cost, it can be claimed that only workmanship quality was optimized in these studies. In other words, it was accepted that the workmanship quality will decrease by crashing the time.

2. **Discrete approach:** The first study with this approach, which also provided a basis for the other ones, was conducted by El-Rayes and Kandil. In this approach it was assumed that TCQ of an activity appears discretely depending on the construction method, crew formation, and crew overtime policy that will be utilized for that activity. To simplify the calculations, these three decision variables were combined into a single variable called resource utilization. Differently from the continuous approach, in discrete approach, the performance quality of a project was optimized. For digitizing the quality, some estimative

quality indicators were considered. For example, El-Rayes and Kandil [1] accepted compressive strength, flexural strength, and ride quality as quality indicators for concrete pavement. Since all quality indicators of an activity and all activities do not affect the total quality of a project equally, some weights were determined for each indicator and activity to calculate the total quality value.

Although the common purpose of these studies was to optimize TCQ of a construction project, different quality concepts were addressed in these two approaches. As a result, some researchers criticized the studies with different approach. For example, Ghodsi et. al. [10], who used the continuous approach, stated that the discrete approach makes the problem complicated to solve because gathering data is not practical for project managers. Especially in projects with many resource utilization alternatives, discrete models lose their applicability. However, Kim et. al. [13], who used the discrete approach, indicated that the continuous approach may be theoretically significant, but not applicable to real problems because contractors do not accept the quality reduction. Similarly, Khang and Myint [9], who applied the continuous model proposed by Babu and Suresh (1996) to a real cement factory construction project, stated that, according to the practicing managers and engineers, the quality reduction due to overtime is negligible and cannot exceed 2±3% even if the maximum amount of overtime is used. In addition, activities with quantitative quality indicators are not greatly affected by the use of overtime. Independently from their time, all the activities must be completed conformably to the contract or science and craft rules.

Expressing the total quality of a project with a simple value is another issue that can be criticized in both approaches. As mentioned before, quality has many dimensions, and for a common perception, all the dimensions should be perceived same among project participants. In other words, if the quality is expressed by a simple value, participants cannot clearly find out which quality indicator or activity reduces the total quality and whether the quality level obtained will satisfy the expected project performance.

Finally, in most of past studies, impacts of construction materials on TCQ were not taken into account completely during the data formation process. As an exception, El Rayes and Kandil considered different strengths of concrete as material alternatives in a highway construction project. As known, building projects are the most common project type in the construction industry, and in such projects, many construction materials which serve to the same purpose can be utilized. Technical specifications of these materials directly affect TCQ of an activity and thereby the total TCQ of a project. For example, according to the Unit Price Analyses of the Ministry of Environment and Urban Planning in Turkey, using gas concrete bricks instead of clay bricks will shorten the duration of the wall building activity by 40%. In this context, besides the crew formation and crew overtime policy, utilizing alternative materials should also be evaluated for crashing the project time. Similarly, using alternative construction materials will also affect the indirect and maintenance costs of a project as well as direct costs of activities. Finally, attributes such as aesthetics, comfort, insulation, strength, and lifetime of alternative construction materials vary. Therefore, each material will compensate project requirements in different quality levels. In this context, it is argued that for an effective TCQ trade-off analysis, the use of alternative construction materials should also be included in the optimization process.

3. Development of a New Methodology

In the literature, the parameter 'material' was neglected and only crew formation and crew policy were included in the formation of alternative resource utilizations. In the current study, it is argued that alternative construction materials should also be included in the resource utilization formation and hence a two-step methodology was introduced. In the first step, effects of alternative construction materials on TCQ of a project under the same conditions should be compared. Toward this aim, alternative resource utilizations of an activity should have the same crew formation and crew policy. The main purpose of the first step is to determine which material will be used in activities. In fact, the determination of materials will also give an idea of the expected quality of a project. In other words, since the quality is determined at the end of the first step, it should not be included in the second step. The second step should only start if project participants attempt to crash the time or reduce the cost of the optimum construction schedule obtained by the first step. Therefore, in the second step, a time-cost trade-off analysis should be conducted by considering alternative crew formation and crew policy. Since in the literature there are numerous studies about the time-cost trade-off problem, only the first step will be outlined in this study.

Unlike the models developed in the literature, in this methodology, it is argued that estimative quality indicators which constitute the total quality of a project should be calculated separately. This approach will create a common perception of quality among project participants, and hence, an effective trade-off analysis can be conducted. On the other hand, the performance delivered throughout the lifecycle of a building determines its quality. In this regard, it was assumed that independently from their intended use, common quality indicators of buildings are change order or maintenance cost and annual energy need, all of which depend on their lifetimes. Similarly, it was also accepted that the time-cost curve and daily number of labor would affect the project management quality. Under these assumptions, besides time and cost, some other parameters such as the number of labor, lifetime of the construction material, change order or maintenance cost of the material, and technical data concerning the building insulation, should be included in each alternative resource utilization data.

In the literature, the main optimization methods for the model development were linear programming and metaheuristic algorithms. As known in the linear programming, only one function can be optimized under some constraints. In this respect, in previous studies, three different models were developed representing each objective. Therefore, these three objectives were not optimized concurrently. Instead, only one objective was optimized under certain values of the other two. However, metaheuristic algorithms allow multi-objective optimizations. In these methods, the solution set is created by the model [14] by searching near optimum solutions [15]. This means that, for each objective, the upper and lower boundary is determined by the model and alternative schedules which are not within boundaries are not included in solution sets as shown in Figure 1. However, in fact, there is time and budget limitations devoted for each project, together with an expected quality level after completion (Figure 2). In this context, it was argued that the devoted time and budget are upper boundaries of a project, and each alternative schedule which lies under these boundaries should be included in the solution set. In addition, to calculate the time depending the indirect cost and change order or maintenance cost of each alternative schedule, both the expected daily cost of a project and the lifetime of a building should be included in project-related data. In this regard, at the end of the methodology, alternative schedules with different time, cost, and quality indicator values, which also satisfy the project's devoted time and budget, will be generated by considering project- and activity-related data as shown in Figure 3.

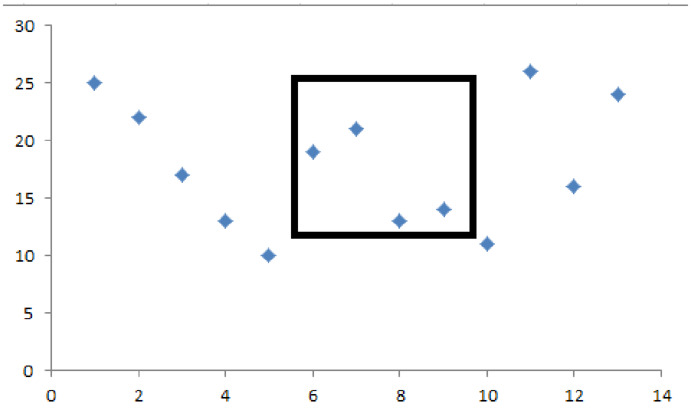

Figure 1. An example of the solution set of metaheuristic algorithms

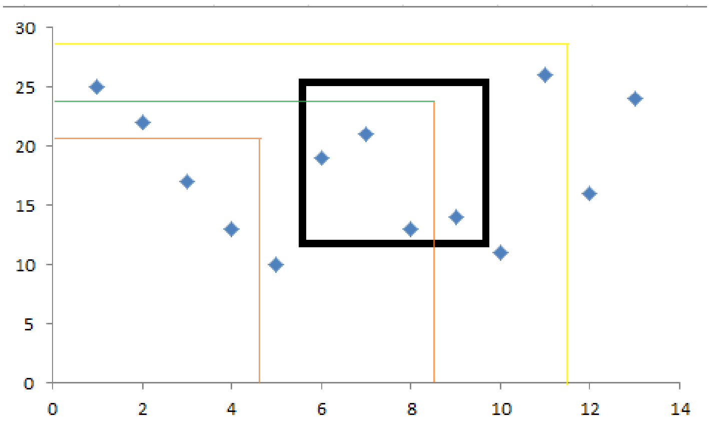

Figure 2. An example of the solution set of new methodology

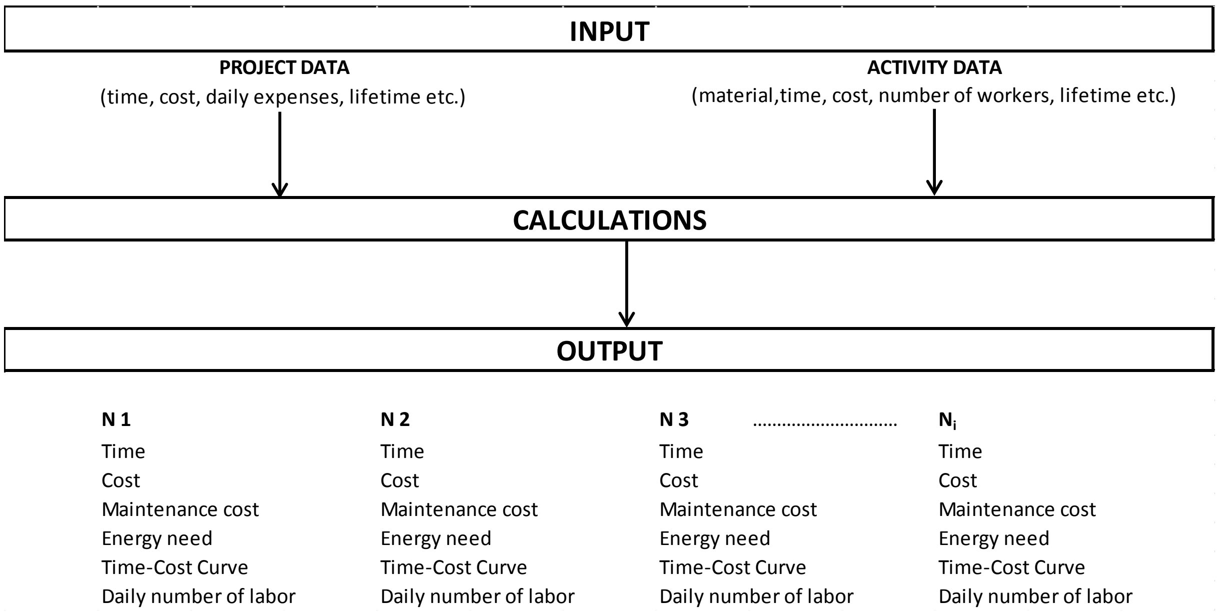

Figure 3. The optimization process of the newly developed methodology

4. Conclusion

Together with the expected quality after completion, the devoted time and cost determines the scope of a project. In this regard, the main objective of project management is to finish a project within its scope. However, in today's construction industry, either the high variety of construction materials or numerous alternatives of crew formation or crew policy allow to use a large number of resource utilizations in construction projects. In addition, the complexity of construction projects, mainly caused by relations among construction activities, makes a complicated environment for evaluating all of alternative resource utilizations during the planning process. To overcome these difficulties, many researchers developed different trade-off models by using different optimization methods. In these models, alternative resource utilizations were considered, and as a result, different construction schedules with different TCQ values were obtained. However, in most of past studies, alternative construction materials were ignored during the formation of resource utilizations, and accordingly, the effect of construction materials on the total TCQ was left out of assessment. Similarly, although quality has many dimensions and is open to the subjective perception among different individuals, the total quality level of projects were expressed by a single value.

In this study, it was aimed to outline a new two-step methodology to overcome the deficiencies determined in the literature. According to the new methodology, in the first step, effects of construction materials on time, cost, and estimative quality indicators of a project should be compared under the same crew formation and crew policy. In fact, at the end of the first step, besides construction materials, the expected quality of a project will also be determined. Therefore, the quality should not be included in the second step. The second step should only be started if the planning engineer wants to make some changes on time and cost of the optimum schedule obtained from the first step. In this context, only time and cost of a project should be optimized concurrently by considering alternative crew formation and crew policy for each activity.

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Factors Affecting Labor Productivity: Perspectives of Craft Workers

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Abstract

Labor productivity has a significant impact on time, cost, and quality of a construction project. Especially the competitive environment of the construction industry forces construction companies to increase their labor productivity values in order to keep their positions in the industry. In this respect, identification and evaluation of factors that affect the labor productivity becomes a crucial issue for industrial practitioners. In the academic literature, there are many studies that investigated these factors and their relationships with the labor productivity. In these studies, the factors were categorized under different groups and ranked according to their importance levels. However, in most of these studies, both the standard deviation among these factors under the same group and the mean value of each group were neglected. In addition, perspectives of managers were taken into account in general while those of craft workers were ignored. The aim of the current study is to re-evaluate the factors under the same groups by considering their standard deviations and mean values from the craft workers' point of view. For this purpose, after a detailed literature review, 37 factors were identified and categorized under four groups such as organizational, economical, physical, and socio-physiological factors. A questionnaire survey were then applied to craft workers to obtain the necessary data which was analyzed by means of the Relative Importance Index (RII) technique. The results revealed that, although the ranking of the factors remained the same, their importance levels have changed

Keywords: Labor productivity, craft workers, Relative Importance Index (RII), construction management.

1. Introduction

Construction projects are accepted as prestigious in many countries and the industry makes a significant contribution to the national economics [1]. For example, in developed countries, construction industry constitutes approximately 10% of the national income [2]. Besides its economic size, construction industry also provides employment with rates of 7 % and 8 % in Europe and USA, respectively [1,3]. However, the economic contribution of construction industry is more significant in developing countries compared with developed ones [4].

Although, construction industry made an appreciable improvement dependently to the technological development [5], non-value adding activities still comprises 50 to 70% of work time in a typical work site [6]. Therefore, labor productivity becomes one of the most important factors that affect both time and cost performances of the construction projects [7].

In this study, it was aimed to introduce the factors affecting labor productivity in Turkish Construction Industry by considering craft workers' perspectives. For this purpose, 37 different factors were analyzed under 4 factor groups named as organizational, economical, physical and socio-psychological. In addition, the distribution of each factor within a group was examined by statistical analysis.

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2. Literature Review

Construction industry is mostly defined as a labor intensive industry. Therefore, labor productivity became a crucial issue for the profitability of the construction projects [8]. Similarly, due to the industry's economic size, an increase in labor productivity will also make a significant contribution to the national income. Accordingly, examining the factors affecting labor productivity attracted the attention of many researchers and numerous researches were conducted. Actually, these factors are local. In other words, factors may vary from region to region, from project to project and even on the same project depending on different conditions [9]. Therefore, in the literature most of the studies were conducted in different countries.

In these studies, different perspectives of different project participants such as project managers, contractors and craft workers were considered. Although, the number and groups of factors differ in each study, data collection and ranking methods are considerably similar. In Table 1 some of these studies and their results are summarized.

As seen in Table 1 these studies were mostly conducted in undeveloped or developing countries. Except Jarkas and Radosavljevic [13], the other researchers investigated the factors by categorizing them under different factors groups. Similarly, Jarkas et. al. [10] analyzed demotivational factors under a simple factor group. RII was the dominating method used for ranking these factors in these studies.

The results of these studies proved that most influencing factors varies from region to region. For example, different two studies conducted in Kuwait and Qatar by the same researchers revealed different results. The most effective factor affecting labor productivity in Kuwait was found as "clarity of specifications" while in Qatar it was "skill of labor" [15, 16]. Similarly, "unavailability of material on time at the workplace", "payment delay", "competence of project manager", "rework", "lack of financial incentive scheme" and "labor experience and skill" factors were evaluated as the most influencing factors in India, Kuwait, Lithuania, Palestine, Qatar and Egypt respectively [8,10,11,12,13,14].

Besides factors, factors groups also varied from region to region in these studies. "Management factor group", "managerial factor group", "project related factor group" "labor group", "technological factor group" and "supervision factor group" were evaluated as most significant factor groups in Egypt, Palestine, Lithuania, Qatar, Kuwait and Indonesia, respectively [8,11,12,15,16,17]

Kazaz et al [18] investigated 37 factors categorized under four factors group by considering managers' perspectives in Turkey. The results revealed that organizational factors group and quality of site management was rated as the most effective factors group and factor, respectively. In this study, it was aimed to investigate these 37 factors by considering craft workers' perspective.

Table 1. Literature Summary of the Factors Affecting Construction Labor Productivity

Country	Researchers	Years	Number of İnvestigated Factors	Number of İnvestigated Factor Groups	Ranking Methods	Results
Egypt	El Gohary and Aziz [8]	2014	30	3	RII[a]	Labor experience and skills were ranked as the most important factors and management factor category was determined the most effective group.
Qatar	Jarkas et al.[10]	2014	38	1	RII[a]	Lack of financial incentive scheme was ranked as the most effective factor.
Palestine	Mahamid [11]	2013	31	5	II[b]	Rework was rated as the most important and weather changes was rated as the least important factors. Managerial factor group was rated as the most effective group.
Lithuania	Gudiene et al.[12]	2013	71	7	RII[a]	Project related factor group was rated as the most significant group and competence of project manager was rated as the most effective factor.
Kuwait	Jarkas and Radosavljevic [13]	2013	23	-	RII[a]	Payment delay was rated as the most significant factor on labor productivity.
India	Thomas and Sudhakumar [14]	2013	44	10	II[b],FI[c],SI[d]	Unavailability of material on time at the workplace was rated as the most effective factor.
Qatar	Jarkas et al.[15]	2012	35	4	RII[a]	Skill of labor and labor group was rated as the most effective factor and factor group, respectively.
Kuwait	Jarkas and Bitar[16]	2012	45	4	RII[a]	Clarity of technical specifications was rated as the most significant factor and technological factor groups was rated as the most significant group.
İndonesia	Soekiman et al. [17]	2011	113	15	RII[a]	Lag of material was rated as the most effective factor and supervision group was rated as the most effective factor group.
Turkey	Kazaz et al. [18]	2008	37	4	RII[a]	Organizational factor group was determined as the most effective group and quality of site management was rated as most influencing factor.

a: RII (Relative Importance Index) b: II (Importance Index)c: FI (Frequency Index) d: SI (Severity Index)

3. Methodology

The results of the studies conducted by considering craft workers' perspective revealed that craft workers can better assess the factors affecting their productivity [19]. In this sense, in this study the factors determined by Kazaz et.al [18] were re-evaluated by considering craft workers' perspectives. Kazaz et. al [18] determined 37 different factors and categorized them under 4 groups named as organizational, economical, physical and socio-psychological. Then, these factors were organized on a 5-point Likert-scale where 1 and 5 represents "not significant" and "extremely significant", respectively. Additionally, in this study an open-ended question was also included to the questionnaire to determine whether there exist other factors in craft workers' perspective. The questionnaire was administered face-to-face to 126 craft workers employed in 4 different construction projects in Turkey.

The results of the questionnaires were statistically evaluated by using the Relative Importance Index (RII). In this context, first RII scores of each factor and then the mean RII scores of each factor group were determined. In addition, standard deviation and coefficient of variation of each group were also calculated. The numeral interval of RII method used for 5-point Likert scale is shown in Table 2. After, each factor was ranked according their RII scores under each factor groups. The distances between each factor's RII score and weighted mean of each group were also determined. Finally, factors with a distance of one and two standard deviation were categorized under the same group.

Table 2. Numeral Intervals of RII Methods

Min RII Points	Definition	Max RII Points
1,00	not significant (NS)	1,80
1,80	somewhat significant (SS)	2,60
2,60	Significant (S)	3,40
3,40	very significant (VS)	4,20
4,20	extremely significant (ES)	5,00

4. Results

The Test of Internal Consistency was used to test the reliability of the questionnaire. To be reliable, the Cronbach's alpha value, which is calculated at the end of this test, must be range between 0,600 and 1,000 [20]. In this study the Test of Internal Consistency was conducted for each factor group and the Cronbach's alpha values of socio-psychological, economical, physical and organizational factor groups were calculated as 0.670, 0.664, 0.788 and 0.646, respectively which were in the accepted interval.

The results of the questionnaire revealed that according to the craft workers' perspective working in social insurance factor which was categorized under economical factors group was the most important factor affecting their productivity with a RII score of 4,68. On the other side, organizational factors group turned out to be the most influencing group with a weighted mean score of 4,06. In Table 3 analyze results of the factors and factor groups are summarized.

Table 3. Ranking of Factor Groups

Name of Group	Number of İnvestigated Factors	Median RII	Effect Level	Rank	Standard Deviation	Coefficient of Variation
Organizational	10	4.09	VS	1	0.45	0.11
Economical	6	4.02	VS	2	0.95	0.24
Socio-psychological	12	3.54	VS	3	0.62	0.18
Physical	9	3.40	VS	4	0.48	0.14

Mean RII score, standard deviation and coefficient of variation values are used to interpret the distribution of factors, compactness ratio and degree of homogeneity of each group [11]. A high compactness ratio of a group increases the consistency of the factors within the group [11]. Figure 1 illustrates dispersion of influencing factors under each factors group in accordance with the mean RII scores.

Figure 1. Dispersion of Productivity Factors

The questionnaire results revealed that organizational factors group has the highest weighted mean score and the lowest standard deviation compared to the other ones. This result also establishes that the compactness ratio of the factors within this group is high. In addition, 4 factors' (camping conditions, quality of site management, systematic flow of work, relaxation allowances) RII score were above the weighted mean of the group while 5 of them namely; site layout, supervision, occupational education and training, crew size and efficiency and firm reputation below. 3 of the factors namely; occupational education and training, crew size and efficiency and firm reputation, which RII scores were below the weighted mean of the group, were located in a distance more than 1 standard deviation. Therefore, it can be deduced that these factors have less influence on labor productivity compared to the other factors within the group according to the craft workers.

In economical factors group, which contained 6 factors, 5 factors namely; working in social insurance, on-time payment, amount of pay, discontinuity of work and incentive payments were located above the weighted mean with approximate RII scores. This result shows that the importance degrees of these factors were perceived as same by craft workers. Only union membership factor was located about 2 standard deviation distance below the weighted mean. Although, 5 factors, which were above the weighted mean, showed a high compactness ratio, the distance of the union membership factor affected the standard deviation and coefficient of variation of the group. Therefore, economical factors group had the highest standard deviation and coefficient of variation among the factors groups.

In socio-psychological factors group 4 factors namely; health and safety conditions, work discipline, social activity opportunities and distance from home were located above, 4 factors as; cultural differences, worker participation in decision making, sharing problems and their results and creating competition were located below and 4 factors namely; distance from population centers, relation with workmates, giving responsibility and work satisfaction were located around the weighted mean value of the group. 2 of the factors (health and safety conditions and work discipline) were located in a distance of more than 1 standard deviation and hence, were accepted as very important by the craft workers compared to other ones. On the other hand, the factor with lowest RII score (creating competition) was located more than 2 standard deviation below the weighted mean and was perceived as insignificant by craft workers.

In physical factors group 5 factors namely; weather conditions, overtime, schedule compression, design complexity and disruptions were located above and 4 factors namely; error tolerance, site congestion, working at similar activities and shift were located below the weighted mean value of the group. The most important factor (weather conditions) according to craft workers' perception had a distance of 1,5 standard deviation from the mean value. Similarly, the factor (shift) with the lowest RII score was located about 2 standard deviation distance below the mean value.

5. Conclusion

Labor productivity has a big impact on the profitability of construction projects and hence, this topic has attracted the attention of many researchers. Although, there are numerous studies which investigate the factors affecting labor productivity, in most of them the factors were not grouped under different factor groups. In the studies, in which the factors were categorized, the dispersion of the factors within a group was usually neglected.

In this study, it was aimed to analyze the dispersion of the factors within a group and the compactness of each factors group. For this purpose, a questionnaire consisting of 37 factors categorized under organizational, economical, physical and socio-psychological factors group was administered to 126 craft workers employed in 4 different construction projects. The results revealed that although 3 factors were located in a distance more than 1 standard deviation above the weighted mean value, organizational factors group has the highest weighted mean and lowest standard deviation values. Therefore, factors under organizational factors group are perceived as equal important by craft workers. Similarly, in both economical and physical factors groups, the factors were also perceived as equal important by craft workers. Only, factors categorized under socio-psychological factors group had different importance degrees according to craft workers' evaluation.

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Defining a Mathematical Function for Labor Productivity in Masonry Construction: A Case Study

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Abstract

Labor productivity has a profound impact on construction management. The accurate prediction of productivity is essential to effectively plan operations that depend on time and cost and is critical for the success of a construction project for both the contractor and the owner. However, predicting productivity of operations is challenging due to the multiple characteristics of workers, the interrelationships between workers, and the site conditions that impact the performance of crews and affect project goals. This paper proposes a methodology to quantify the factors that affect productivity in masonry construction. We have considered three factors: compatibility, suitability, and craft. Standardized data-collection techniques are used to consolidate data from three masonry sites and mathematically define a productivity function that relates workers characteristics and crews with site conditions. The function, increasing in its arguments, determines the factors that most affect masonry productivity and the factor's effects. The most interesting part is to be able to identify the convexity properties of this function because its theoretical interpretation will have implications on the impact of the superintendent's decisions when forming crews. The proposed mathematical function can enable superintendents to better plan, schedule, and manage masonry crews.

Keywords: crew formation, labor management, masonry construction, productivity function

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1. Introduction

Labor productivity is one of the key factors affecting the overall performance of a construction project [1]. Labor costs usually account for about 30-50% of the total project costs [2] and labor is considered the strategic resource in any project for ensuring improved productivity and industry competitiveness [3, 4]. By effectively managing labor, the productivity of all the other inputs can be simultaneously enhanced and all of the benefits available through improved productivity can be realized. Crew formation is one of the key tasks in labor management [5]. The process of selecting the workers in a crew and assigning crews to different tasks is crucial for ensuring the success of a construction project and improved labor productivity. Florez [6] conducted a review to understand the functioning of masonry crews and determine the factors that impact the productivity of crews. Through extensive site observations and interviews with masonry practitioners, it was found that typically the superintendent in the jobsite considers three factors (that impact productivity) when grouping workers in crews: compatibility, suitability, and craft. This paper aims to define a function that determines the three factor's effects on productivity. The function alongside its theoretical interpretation will provide a means for determining the extent of the superintendent's decisions and can become a powerful tool for the process of planning and managing masonry crews.

2. Masonry construction

Masonry construction is labor-intensive. Processes involve little to no mechanization and require a large number of crews made up of workers with diverse skills, capabilities, and personalities [7]. In masonry construction, management of labor is one of the key factors to balance production and quality [8]. Tasks may require several

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crews with diverse skills to be completed and crews need to be scheduled to ensure an efficient output and adequate control [4]. This allocation process in masonry construction is challenging. Every time a wall section or part of a wall section is completed, the labor configuration is reorganized [9]. This results in temporary crews that need to be constantly moving and the superintendent is responsible of re-organizing the crews to make sure the masons selected to build the walls have the required characteristics to produce good quality work within the given time constraints.

2.1. *Factors that impact crew formation*

Results from the exploratory study in [6] indicate there are different characteristics of masons that need to be considered because these have an impact on the quality of the work and the productivity of a crew. These criteria are used by masonry practitioners in forming crews and are used as guidelines when the superintendent is in the jobsite trying to group workers to form the most efficient crew. The three factors that impact productivity found in [6] are detailed below:

- Compatibility: masons have different personalities, ways to work, and get things done. Some masons work well together, but some masons just do not work well with certain other masons. They just do not get along and when they work with each other they seem to get less productive. The superintendent tries to form crews with workers that are compatible because grouping masons that work well together can increase throughput [10].
- Suitability: masons have different specialties and can be more suitable to work in a specific type of wall. Some masons are very good levelling and plumbing and therefore are efficient working on wall sections that require a high demand of technical work (e.g., openings, intricate corners, details, building leads, penetrations). Other masons are not good with the level and the plumb but are very efficient working in the line and in non-technical work (e.g. straight walls or walls with little to no openings). The superintendent tries to assign a mason to a wall that matches the specialty of the mason to the type of work required in the wall.
- Craft: masons learn (and know) how to lay brick and block but are usually faster at one craft than the other. Some masons are good at handling smaller units and are more detailed so they are better brick layers, whereas some masons are stronger and are better at laying block. In other words, in masonry there are bricklayers and there are block masons. The superintendent tries to assign a mason to a wall section where the material match the craft the mason is more efficient at.

3. Managing and scheduling labor in masonry

The proposed model is based on the mixed-integer program by Florez [6]. The model assigns crews to minimize the time to build walls in a masonry project. The allocation process consists of determining which crew is going to be working in which wall and at what time. Each wall demands a number of masons and each crew is comprised of a certain number of masons, so the model determines which crew from the crews available is assigned to each wall. To build the schedule, the model uses binary decision variables to define the times each crew is working in a specific wall. Note that the model only allows *go-no-go* decisions, that is, walls cannot be partially built and once they are in progress are not interrupted. The reporting module of the optimization model is a detailed schedule of the times to start the walls, the number of masons, and the crew configuration under the optimal schedule.

Mathematically, the model's objective is to minimize the total execution time to finish the walls. Aside from the structural binary variables y_{ijt} that determine if wall i is assigned to crew j and scheduled to start at the beginning of time t, the decision variable $C_{\max}$ represents the makespan of the project schedule. The latter variable allows us to define the proposed objective function:

$$\min = C_{\max} \tag{1}$$

where (1) minimizes the total execution time when scheduling all the walls. To accomplish this objective, it is important to include in the model the following constraints:

$$C_{\max} \geq (t + v_{i,j} - 1) \cdot y_{i,j,t} \qquad ; i \in I, j \in J, t = 1,\ldots,T \tag{2}$$

where v_{ij} is the time it takes crew j to finish wall i. The proposed model also defines the following set of auxiliary variables. Structural binary variables x_{ijt} denote if crew j is assigned to wall i at time t. In addition the (auxiliary) binary variables z_{ij} determine if wall i is assigned to crew j. Along with objective (1) the model also includes the following constraints:

$$\sum_{t=1}^{T}\sum_{j\in J_i} y_{i,j,t} = 1 \qquad , i \in I \qquad (3)$$

$$\sum_{i\in I} x_{i,j,t} \leq 1 \qquad ; j \in J, t = 1,\ldots,T \qquad (4)$$

$$\sum_{j\in J_r}\sum_{i\in I} x_{i,j,t} \leq 1 \qquad ; t = 1,\ldots,T, r \in R \qquad (5)$$

$$z_{i,j} = \sum_{t=1}^{T} y_{i,j,t} \qquad ; i \in I, j \in J \qquad (6)$$

$$v_{i,j} \cdot z_{i,j} = \sum_{t=1}^{T} x_{i,j,t} \qquad ; i \in I, j \in J \qquad (7)$$

$$v_{i,j} \cdot y_{i,j,t} \leq \sum_{\hat{t}=t}^{t+v_{ij}-1} x_{i,j,\hat{t}} \qquad ; i \in I, j \in J, t \in T \qquad (8)$$

The set of constraints in (3) guarantees that every wall is built. The set of constraints in (4) guarantees a crew builds at most one wall at any given time while the set of constraints in (5) guarantees that a mason is not working in two crews at any given time. The set of constraints in (6) activates the corresponding z variables when a given wall is assigned to a crew. The set of constraints in (7) and (8) guarantee that a crew that is assigned to a wall stays in the same wall until the wall is finished. Note that a crew works during consecutive time periods so no interruptions are allowed. In addition, note that the objective function (1) minimizes the total execution time, ultimately aiming for increased productivity. The mathematical program presented could be further extended to incorporate additional considerations such as precedence relations between the walls and cost constraints, detailed in Florez [6].

3.1. *Labor productivity function*

Let's look closer how to determine the number of time periods that a crew j takes to build a masonry wall i, that is parameter v_{ij}, which is calculated using the productivity function. As detailed in Section 2.1, it was found that the productivity of a crew is affected by the compatibility (c_j), the suitability (s_j), and the craft (k_j) of the crew. Note that the higher the compatibility, the suitability or the craft the higher the productivity. Therefore, the productivity function is expected to be a function of these three parameters, $F(c_j, s_j, k_j)$ and common sense dictates that F should be an increasing function of its arguments,

$$\partial F/\partial c_j \geq 0, \quad \partial F/\partial s_j \geq 0, \quad \partial F/\partial k_j \geq 0$$

In Florez [6], the productivity function is given by equation (9). The function was used in a medium size construction site and its results were similar to the ones expected (with the data in hand) so these assumptions apply.

$$F = 1/3\left(c_j + s_j + k_j\right) \qquad (9)$$

This can be considered a first order approximation to F (Taylor polynomial of degree 1), and in this case we justify its use by the fact that the site area where it was used was of moderate size. In a more general context we could have used as a first approximation the more general equation (see equation 10):

$$F = \alpha \cdot c_j + \beta \cdot s_j + \lambda \cdot k_j$$

It may be expected that α, β, λ might be different, but further investigations are needed to properly define these parameters. We expect F to be nonlinear, and its nonlinearity should manifest itself in more complex building scenarios. In the last section we discuss the possibility that F satisfies universal convexity properties. To calculate the time that it will take crew j to build a wall, lets define u_i as the total number of units in wall i. The time is given by equation (11):

$$v_{ij} = \frac{u_i}{F(c_j, s_j, k_j)} \qquad (11)$$

This study is proposing a productivity function (alongside the model) in terms of the compatibility, suitability, and craft scores of the masons in a crew. Function F given by equation (9) was proposed for a number of reasons:

- F is a linear approximation since it is expected that the suitability, compatibility, and craft scores will contribute to affect the productivity. It is not the product of the scores because it is not expected that these may have such a significant reduction in the productivity. If it had been the product of the factors, even for a slight reduction of the factors the total productivity will be considerably reduced which does not truly reflect the capabilities of the masons. The masons are qualified to place units in a wall because they are trained to be masons.
- The coefficients of the three factors (compatibility, suitability, and craft) in the function are assumed to be the same since without any further information it is natural to propose that the factors influence the productivity equally. Therefore, the productivity will be the mean value of the factors. In this particular case [6], there is no more data in hand so these assumptions apply. Note that the case study was developed in a site of moderate size. The function and its coefficients may change given a different size and also further studies can be developed to determine the coefficient for each one of the factors.

3.2. *Convexity properties of the productivity function*

It is expected that when the function F is expressed in terms of compatibility (any other parameters fixed), then it will have a universal form. The shape of this function may be of interest, as it may have implications over how careful the selection of crews must be. Since there is no way, founded on theoretical grounds to determine the shape of the productivity function in terms of compatibility, an example is used to show how this information could be of use. Note that the shape could be determined by experiments using a sensitive enough Likert scale.

Let us assume that the shape of the productivity function F has been determined to be concave as shown in Figure 1. More rigorously, F satisfies equation (12) for all the values that it is defined and it may or may not be a continuous function, as compatibility can take on values on a discrete scale. Therefore, there is a value of compatibility c_0 (see Figure 1) above which, the process of selection of the crews will not produce a significant increase in productivity. However, below this level much more attention should be paid to the selection of crews as this could be meaningful for the productivity output.

$$F\left(s \cdot c_1 + (1-s) \cdot c_2\right) \geq sF\left(c_1\right) + (1-s)F\left(c_2\right) \qquad ,0 \leq s \leq 1 \tag{12}$$

In Figure 1, notice that the difference in productivity for the crews whose compatibility is below c_0 is much bigger than the difference in the case of the crews whose compatibility is above c_0. For instance, if crew 3 were to be chosen over crew 4, the impact on productivity would not be as significant as if crew 1 was chosen over crew 2. So in this case, having to select two crews to optimize productivity (assuming there are only two choices: crew 1 and crew 4 or crew 2 and crew 3), the selection could be the two crews whose compatibility is close to the c_0 value, instead of trying to select one with an outstanding score and one with a score far below c_0. So if the selection is between crew 1 and crew 4 or crew 2 and crew 3, the heuristic would make the second choice. This will be of course reflected in the choices made by the model in this paper; but the choices made following this heuristic in more complicated examples should not differ significantly from the optimal one. These results might be good enough for practical purposes and could be used to simplify the optimization process or even to make a rough guess on how to form the crews.

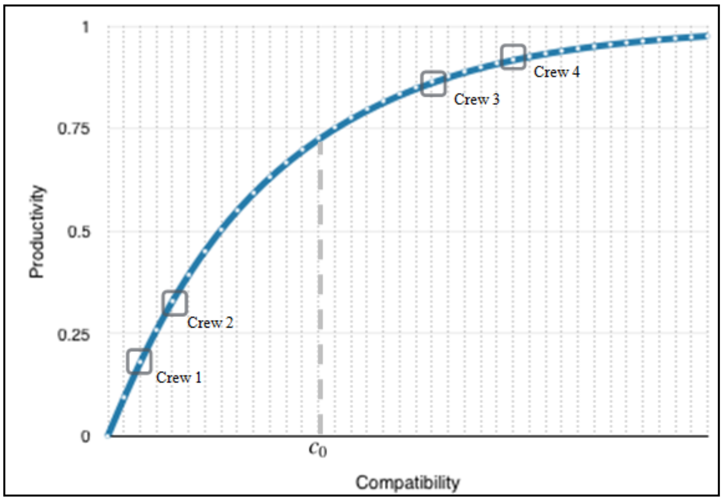

Figure 1- Productivity function

The example above also shows that the simple fact of knowing the shape of the productivity function (not without knowing its exact values), may serve as an heuristic to make decisions on how to form crews. As shown above, just knowing that the productivity function is concave, it is preferable to have crews that have medium/average compatibility scores than having some that have mediocre compatibility scores and some that have outstanding compatibility scores. If the productivity function were convex, a better strategy would be to start choosing as many outstanding crews as possible, not paying too much attention to the fact that some crews may have mediocre compatibility scores. Note that the more concave or the more convex the productivity function is (as a function of compatibility), the better these heuristics will work. However, the closer the productivity function is to a linear function, working with a full-fledged optimization model becomes a more critical issue.

On the other hand if there is a more precise knowledge of the productivity function, the optimization process proposed could be modified not only in the sense of giving heuristics as above. Indeed, in simple cases instead of going for a full optimization with all the constraints that might be added to the model to make it as precise as possible, the process could be simplified by just maximizing the number of crews that have a compatibility score above a certain threshold (eliminating some other constraints) or by introducing penalizations for not using crews with compatibility scores close enough to a certain threshold. In other words a full-fledged model for a simple construction case can be thus simplified without losing significant information and this can be done in principle by a capable superintendent, who has been taught to how do so.

4. Conclusions and discussion

The crew allocation process in masonry construction is challenging. Multiple masons with different skills, capabilities, and personalities are present in the jobsite at any one time and the superintendent needs to consider the characteristics of the masons to balance between the complexity of the job, the quality of work and the need for high production rates. A mixed-integer program was developed to allocate crews and schedule walls. The model not only determines which crew is assigned to each wall but also the masons in a crew and the times the crews are working in a specific wall. Alongside the model, a productivity function was proposed to mathematically define the factors that most affect masonry productivity and the factor's effects. Through a series of examples it was shown that the shape of this function is of interests because it may have implications over how careful the selection of crews must be. Such findings can help understand what aspects for instance influence crew formation and what should be the focus of managers when forming crews in construction and other group teams.

Consequently the question we must raise now is the following: is the shape of the productivity function universal? By universal we mean that, aside from its exact values, it does not depend on the building techniques and it will be consistent. In other words, two masons that have the same compatibility would be expected to have a similar productivity record every time they are grouped in a crew. If this universality is found, we believe that it would be an outstanding discovery. We ask the reader to think about the utility function in economics, whose shape is universal (concave), and that it is determined from basic economic principles. Hopefully one day we will find firm theoretical grounds based on the knowledge contributed by other social sciences to predict the shape of our productivity function.

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Should Time be the Only Scale Required for Relationship and Margin Calculations?

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Abstract

Precedence logic's four types of relationships, four types of margins and by simulating the work production through lags present several shortcomings that affect the accuracy of the schedule and margin calculations, as is well documented in the literature. To overcome these gaps, the Chronographic Method has proposed many developments over several years, including allowing for split activities with internal divisions according to quantities. Internal divisions extend the relationships between activities to deterministic and probabilistic point-to-point, by-section or continuous relations, generating realistic dependencies and new types of floats (Complete, Start, Finish and Partial floats). Activities and divisions may also have external and internal scales. External horizontal scales may designate the measuring unit of the x-axis for an orthogonal system and should be unique for the entire project (e.g. time that defines the external horizontal scale unit of the bar chart diagram). Internal horizontal scales can be distinct for each activity or section. External and internal scales may be based on time, cost, work progress, quantity, risk or performance. For the purposes of calculation, this paper uses time as the external scale and the amount of work as the internal scale. Relations and margins can then be calculated according to the external scale (time) or the internal scale (quantity). The calculation constraints and project tracking can then be based on either time or quantity. This paper explains this concept and the calculation equations for these new types of margins; discusses the limitations of the traditional margins and the use of time as the only scale required for relationship and margin calculations; and demonstrates the relevance of using other measures, including the amount of work, Site occupations for scheduling calculations. The proposed chronographic logic and margin calculations can then be used to simulate the project's real conditions.

Chronographic method, construction, margin, Precedence diagram, project by [1]

1. Scheduling Logic

The Precedence Diagram Method (PDM) is currently the most widely used scheduling method for construction projects. PDM was originally published by [1] as the Potential Tasks Method and disclosed by [2] under the acronym "PDM". Common scheduling software plans projects using a method that combines the bar chart diagram and precedence logic. The Precedence Method proposes four types of relationships (Finish-to-Start, Start-to-Start, Finish-to-Finish, and Start-to-Finish). However, by using external constraints and lags to simulate production, precedence logic lacks precision: i) via the reverse critical path [3]; ii) when using certain types of relations and delays with multiple calendars [4]; iii) when using lags with Start-to-Start or Finish-to-Finish relations [5]; and iv) when two or more activities depend on each other during the execution process [6].

The shortcomings of using these external precedence relationships to represent interdependencies and overlaps have, in the past, generated studies on the impact of upstream activities on downstream activities. Allen [7] describes the logic based on temporal intervals rather than time points and defines thirteen possible temporal relationships that describe situations from either a static or dynamic perspective. The concept of concurrent engineering has been used to address this problem [8, 9] by proposing an overlapping framework based on activity progress rates, upstream task reliability, downstream task sensitivity and task divisibility. Francis and Miresco [5, 10] have proposed chronographic logic, providing for internal divisions of activities according to quantities while extending the relationships between activities to point-to-point relations and generating realistic dependencies and new types of floats. The Chronographic Model also makes a distinction between two types of lags, that is, the technical lag, such as concrete curing, and the production lag, which imposes partial dependencies in order to simulate production. Song and Chua [11] have presented a temporal logic intermediate function relationship based on an interval-to-interval format. The temporal logic resides within intermediate functions from three perspectives: the construction life cycle of a single product component, the functional interdependencies between two in-progress components, and the availability conditions of an intermediate functionality provided by a group of product components. Lu and Lam [12] have proposed a method that automatically transforms schemes in a PDM network, such as Non-Finish-to-Start (FS) relationships, into their equivalent. A graphical representation bee-line diagram (BDM) using a bee-line relation, has been developed by [13]. The chronographic production-based relation allows probabilistic dependencies between activities, while the production-based dynamic function allows one to follow the interdependencies between the two in-progress activities using sectional mathematical functions [6]. Hajdu [14] has proposed a mathematical model of PDM with point-to-point relations, along with continuous precedence relations for Better Modelling Overlapping Activities [15].

2. Constraints and Internal Float Concept

The Precedence Method proposes four types of relationships (Finish-to-Start, Start-to-Start, Finish-to-Finish, and Start-to-Finish) and defines four types of floats (Total Floats, Free Floats, Interfering Floats and Independent Floats), two of which, the Total and Free Floats, are frequently used. These floats are based on the premise that every activity is a single integral entity. However, each activity also represents an execution process in which different sections are affected differently. To overcome these gaps, the Chronographic Method has led to many developments over the years, including split activities with internal divisions according to quantities. Internal divisions extend the relationship between activities to include deterministic and probabilistic point-to-point relations, along with by-section and continuous relations, while generating realistic dependencies and new types of floats [10]. This new calculation logic, combined with the existing floats, has resulted in the creation of a new margin calculation logic that can simulate actual project conditions.

Figure 1 illustrates the constraints between activities using four examples. Figures 1.a and 1.b have a Start-to-Start link with a lag of 5 days. Figure 1.b shows the internal production rates of these two activities and demonstrates how Sections A1 and A2 are predecessors of Sections B1 and B2, respectively. This type of link presents certain flaws:

- It simulates the work production through lags. The lag stimulates the production under Section A1. Thus, Section B1 is presumed to start after the completion of Section A1. If the production rate of this predecessor section changes (by increasing or decreasing), the duration of the lag will remain unchanged, forcing planners to adjust the duration manually. This is difficult to perceive for larger projects.
- It fails to follow the progress between two activities with an inter-connected execution. In real-life situations, many activities depend on each other during their execution. A relationship that limits only the start or finish of the successor activity is considered insufficient when properly assessing progress. If some changes take place after the relationship's effect, the successor activity will not be affected and the planner will be forced to make modifications manually.

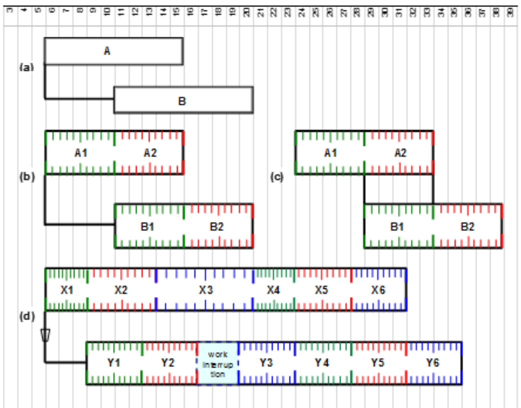

Figure 1: Constraints between Activities

- Margin calculations: Floats will be calculated on the basis of this unique link between Start-to-Start and lag, and may accidentally limit the extension of the predecessor duration. This is clearly explained under Figure 3.a.

The limitations are usually caused by a failure to add resource links and the existence of phantom floats. This is due to the difficulty of retracing these links and their instabilities. Any change in the availability of resources, or even in the production rates, can affect these links. Limitations can also arise through the strict use of external constraints and by neglecting every internal execution process. Finally, by using time as the only scale required for relationships and networks, along with critical paths and margin calculations, the schedule fails to consider other measurements, including workloads and site occupation when scheduling calculations. The proposed chronographic logic and their margin calculations can then be used to simulate the project's actual conditions.

Figure 1.c shows the same example using the chronographic point-to-point logic that permits multiple internal interdependencies between activities. In this figure, the ends of Sections A1 and A2 as predecessors are linked with the start of Sections B1 and B2, respectively. The production-based dynamic function concept [6] suggests replacing the multiple internal interdependencies between activities with a mathematical function associated with a single temporal function, Figure 1.d. This function contains the rules that manage the interdependencies between

the two in-progress activities by tracking the internal variation during production. The internal production of each activity can vary from one period to another, affecting the relative period of the dependent activity, which may be interrupted.

We must differentiate between work interruptions and internal floats. Floats are expected from the planning phase and during scheduling updates. As mentioned above, floats are used to level the resources and optimize the project. Work interruptions are considered as execution constraints. In Figure 1.d, the work is interrupted between Sections Y2 and Y3 in order to comply with the technical constraints caused by slower-than-expected progress in the predecessor Sections X2 and X3. This interruption will not prevent Team Y from performing other work, if possible.

2.1. *Internal Floats*

The Chronographic Method identifies three (3) new external float types: the Complete Float, the Start Float and the Finish Float. These three floats could be partial if applied to a particular activity section. Table 1 illustrates the combination of Chronographic Floats with the two most popular and traditional floats, the Total Float and the Free Float. Note that the Chronographic Floats could also be combined with the Independent and Interference Floats.

Table 1: Combination of Existing and New Floats

	Total Float	**Free Float**
Complete	Complete Total Float	Complete Free Float
Start	Start Total Float	Start Free Float
Finish	Finish Total Float	Finish Free Float
Partial Complete	Complete Total Float	Complete Free Float
Partial Start	Start Total Float	Start Free Float
Partial Finish	Finish Total Float	Finish Free Float

The Complete Float considers the entire activity as a single integral entity. No constraints affect its beginning, end or internal sections differently. The Start Float and the Finish Float are created when the beginning and end of the activity are affected differently. Partial Floats concern every section of the activity and could be Partial Complete Floats, Partial Start Floats or Partial Finish Floats. The comprehensive results of this study can be found in [16]. The Start and Finish Floats are created when one of the two extremities of an activity (or a section) is fixed (or semi-fixed). This means that the end has at least one predecessor and one successor constraint. These relational constraints limit the earliest and latest dates of this extremity, which could be more restricted than the other extremity.

Figure 2 shows examples involving the Start and Finish Free Floats. In Figure 2.a, Activity X has two relationships with its end. The first is a predecessor relationship with Activity B and the second is a successor related to Activity C. These two relationships limit the movement of this end. Thus, the early finish becomes equal to the late finish date of this activity. The start of Activity X possesses different constraints, which leaves greater float at its start. If the duration of Activity X is flexible, it can benefit from this Start Float by starting earlier and decreasing productivity, if necessary.

Figure 2.b shows an example in which Activity Y has a Free Finish Float of 4 days and a Free Start Float of zero days. This activity has two relationships that constrain its start. The first is a predecessor relationship with Activity E and the second is a successor relationship with Activity F. Thus, the early start date becomes equal to the latest start date. The end of Activity Y possesses different constraints, which leaves more floats. If the duration of Activity Y is flexible, it can benefit from this Finish Float by decreasing productivity, if necessary.

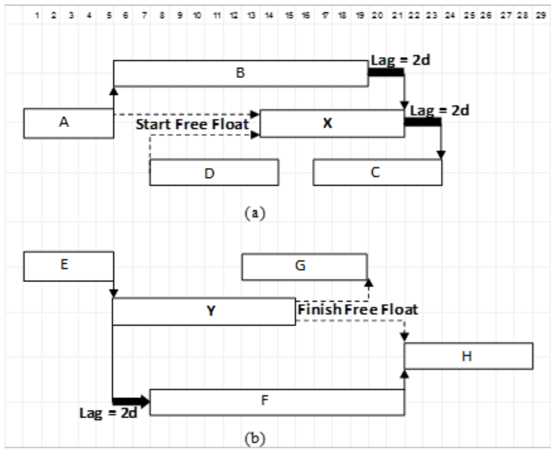

Figure 2: Start and Finish Free Floats

The Start Free Float (SFF) for Activity X is calculated as follows:

$$\text{SFF} = \min \begin{cases} \text{FS} \rightarrow ES_{Activity} - \left(EF_{predecessor} + Lag - 1\right) \\ \text{SS} \rightarrow ES_{Activity} - \left(ES_{predccessr} + Lag\right) \end{cases} = \min \begin{cases} 14 - (5+0-1) = 8 \\ 14 - (8+0) = 6 \end{cases} = 6\text{d} \quad (1)$$

The Finish Free Float (FFF) of Activity Y is calculated as follows:

$$\text{FFF} = \min \begin{cases} \text{FS} \rightarrow ES_{successor} - \left(EF_{Activity} + Lag - 1\right) \\ \text{FF} \rightarrow EF_{successor} - \left(EF_{Activity} + Lag\right) \end{cases} = \min \begin{cases} 22 - (15+0-1) = 6 \\ 19 - (15+0) = 4 \end{cases} = 4\text{d} \quad (2)$$

3. External and Internal Scales

With the Chronographic Method, activities may have external and internal scales. In this paper, external horizontal scales designate time and internal horizontal scales designate quantities.

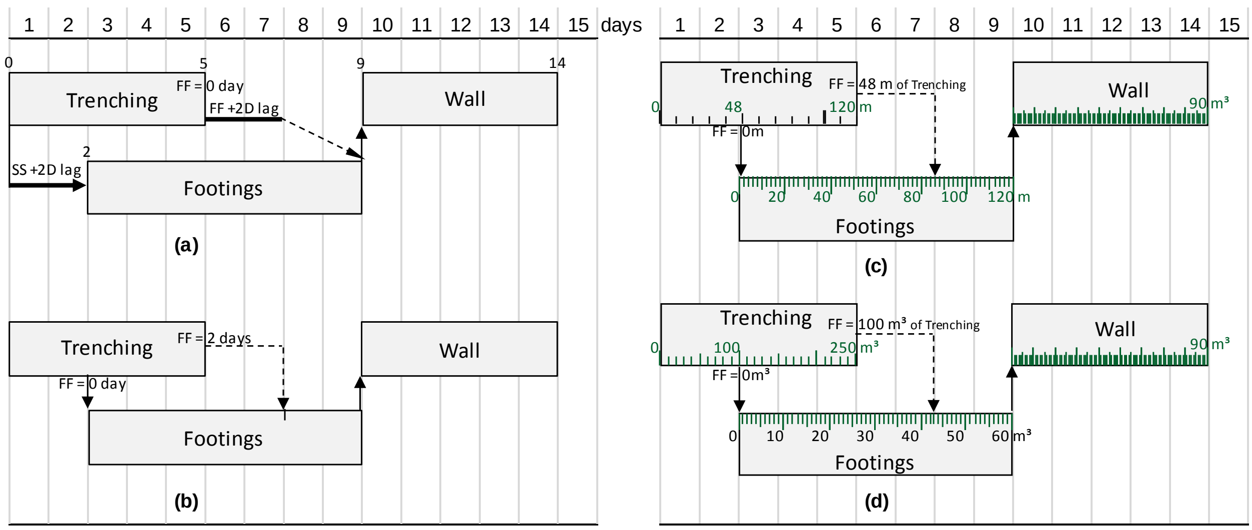

Figure 3: Calculating the Free Float Using the External and the Internal Scales

Activities may also have one or more internal divisions. These divisions could be related to the external scale (time), or the internal scale. They may also be related to the targeted workload and adjusted automatically as a function of production variation rates. Calculation constraints and project tracking can then be based on either time or quantity.

The example presented in Figure 3 schedules the construction of a wall that consists of three activities: Trenching, Footing and Wall. This example illustrates the graphical modeling and calculation of the Free Complete and Partial Floats for the Trenching activity. Figure 3.a illustrates the calculation of the Free Float (FF) with the Precedence Method. In this example, both the Trenching and Footing activities have two links: Start-to-Start with a lag of two days, and Finish-to-Finish with lag of two days. The FF is the smallest float calculated with all links between activities. Thus, the FF of the Trenching activity is equal to zero.

$$FF_{\text{Trenching}} = \min \left\{ \begin{array}{l} \text{1 – Start-to-Start with a lag of two days:} \\ ES_{\text{Footing}} \text{ (Day 2)} - Lag_{SS} \text{ (2 days)} - ES_{\text{Trenching}} \text{ (Day 0)} = 0 \text{ day} \\ \\ \text{2 – Finish-to-Finish with a lag of two days:} \\ EF_{\text{Footing}} \text{ (Day 9)} - Lag_{FF} \text{ (2 days)} - EF_{\text{Trenching}} \text{ (Day 5)} = 2 \text{ days} \end{array} \right\} = 0 \text{ day} \quad (3)$$

However, if the method accepts flexible durations for the activities, a Free Finish Float could be created for the Trenching activity. If the activity duration became flexible, the manager could use the available float of each section in order to optimize the project [10]. In this case, the activity possesses three Free Margins: A Start Free Float (of 0 Day), a Finish Free Float (of 2 days), and a Complete Free Float for the whole activity that is equal to the smallest Free Float, or zero day.

The other three Figures (3.b, 3.c and 3.d) illustrate the links between activities and the float calculations using Chronographic logic with internal divisions and internal and external scales.

When using external scale (Figure 3.b), both the Footing and Trenching activities are linked with to links (Internal-to-Start and Finish-to-Internal). A minimum lead of two days between both activities is required at all times. This means that the Footing activity can only start if a minimum of two days has elapsed from the Trenching activity and must remain at least two days to finalize the Footing activity after the end of the Trenching activity. In addition, there must be a maximum duration of four days between the executions of both activities at all times. This means that the Trenching activity must stop if this duration is exceeded. Thus, floats may differ from one section to another or on every day for a continuous link. For example, the Free Float for the Trenching activity is zero days at the end of the first relationship (Internal-to-Start). Any implementation delay during these initial two days will delay the start of the Footing activity.

$$FF_{\text{1st sec Trench}} = \min \left\{ ES_{\text{Footing}}\text{(Day 2)} - ES_{\text{Trenching}}\text{(2 days)} \right\} = 0 \text{ days} \quad (4)$$

There is a two-day Free Float at the end of the Trenching activity.

$$FF_{\text{end Trench}} = \min \left\{ EF_{\text{1st sec Footing}}\text{(Day 7)} - EF_{\text{Trenching}}\text{(Day 5)} \right\} = 2 \text{ days} \quad (5)$$

or

$$FF_{\text{end Trench}} = \min \left\{ EF_{\text{Footing}} \text{ (Day 9)} - Lead_{\text{Min remain dur. finalize Foot.}} \text{ (2 days)} - EF_{\text{Trenching}} \text{ (Day 5)} \right\} = 2 \text{ days} \quad (6)$$

With the internal scale (Figures 3.c and 3.d), both Footing and Trenching activities are linked in two ways (Internal-to-Start and Finish-to-Internal). There must be a minimum lead of 48 linear meters, or 100 m³ according to the scale, between both activities at all times. This means that the Footing activity can only start if at least 48 linear meters (or 100 m³) have elapsed from the Trenching activity and must remain at least 48 linear meters (or 100 m³) to finalize the Footing activity after the end of the Trenching activity. In addition, there must be a maximum of 96 linear meters (or 200 m³) between the executions of both activities at all times. This means that the Trenching activity must stop if this quantity is exceeded. The Free Float at the end of the first section of the Trenching activity (Start-to-Start relation with a lag of 48 linear meters or 100 m³) is as follows:

$$FF_{\text{1st sec Trench}} = \min \left\{ ES_{\text{Footing}}\text{(48 ml of Trenching)} - ES_{\text{Trenching}}\text{(48 ml of Trenching)} \right\} = 0 \text{ ml}_{\text{ of Trenching}} \quad (7)$$

or

$$FF_{\text{1st sec Trench}} = \min\left\{ ES_{\text{Footing}}(100\text{m}^3 \text{ of Trenching}) - ES_{\text{Trenching}}(100\text{m}^3 \text{ of Trenching}) \right\} = 0 \text{ m}^3{}_{\text{of Trenching}} \quad (8)$$

The Free Float at the end of the first section of the Trenching activity is as follows:

$$FF_{\text{end Trench}} = \min\left\{ EF_{\text{Footing}}(216 \text{ ml of Trenching}) - Lead_{\text{Min remain finalize Foot.}}(48\text{ml of Trenching}) - EF_{\text{Trenching}}(120\text{ml of Trenching}) \right\} = 48 \text{ ml}_{\text{ of Trenching}} \quad (9)$$

or

$$FF_{\text{end Trench}} = \min\left\{ EF_{\text{Footing}}(450\text{m}^3 - Lead_{\text{Min remain finalize Foot.}}(100\text{m}^3 - EF_{\text{Trenching}}(250\text{m}^3 \right\} = 100 \text{ m}^3{}_{\text{of Trenching}} \quad 10)$$

4. Conclusion

The calculation of margins using the external and internal scales may better simulate the project's actual conditions. External and internal scales may be based on time, cost, work progress, quantity, risk or performance. For calculation purposes, this paper uses time as the external scale and workload as the internal scale. This illustrates the calculation of internal and external margins and tracks the interdependencies between the two in-progress activities. This paper presents the impact of the application of chronographic logic and internal and external scales on the critical path and margin calculations. Thus, this paper does not propose a methodology that would optimize the logic, but rather one that would simulate actual on-site conditions as closely as possible in order to yield a more realistic result. In conclusion, the application of the proposed logic permits the tracking of interdependencies between two in-progress activities and yields more realistic results when tracking internal dependencies and margins. These advantages allow the planner to present a more realistic and detailed schedule and to make adjustments when monitoring the project.

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Removing Constraints to Make Tasks Ready in Weekly Work Planning

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Abstract

The Last Planner System (LPS) have been used on construction projects to improve reliable work planning. Lookahead planning is intermediate process that connects the master or phase schedule to the weekly work plan. Construction teams employ lookahead planning to achieve various objectives including a breakdown down of activities into the level of operations, operations design, and constraint removal to make tasks ready for execution. Tasks Made Ready (TMR) measures the performance of lookahead planning in identifying and eliminating constraints to make activities ready for implementation. The purpose of this paper is to study through computer simulation the impact of TMR on task execution, reliability of weekly work planning, and project duration. Results show that TMR is a good predictor of project duration. These results advise planners on the importance of the constraint removal process, how it influences the reliability of construction planning, and its impact on project duration.

Keywords: Constraints, Last Planner System, Lookahead Planning, Tasks Made Ready, Workflow.

1. Introduction

Planning is a crucial determinate of the success of any project. It consists of directing a project to meet its objectives in terms of time, cost, quality, and safety [1]. It follows then that any poor practice related to planning could ultimately lead to the project's failure. The traditional planning techniques, particularly the Critical Path Method (CPM), were criticized and deemed insufficient and inadequate by many researchers [2].

One of the major deficiencies of CPM is that it focuses on the logical dependencies between activities with a disregard for the continuity of workflow among different trades [3]. Another problem with CPM relates to allocating time buffers to cover possible uncertainties in activities [4]. This exercise brings about many constraints and especially prerequisite constraints that can disrupt the continuity of work. With these time buffers, it becomes difficult to determine when a certain activity will finish. This adds to the complexity of making tasks ready when needed resulting in a higher cost and longer project duration.

In the light of these and other inadequacies, the Last Planner System (LPS) has been developed for planning and controlling construction projects. It has been used to ensure and improve the continuity of workflow while increasing planning reliability by minimizing the difference between tasks that are planned and those that are actually completed [5,6].

The LPS consists of four planning phases: (1) *master scheduling* which sets major project milestones; (2) *phase* scheduling which identifies the activities that "should" be done as well as the handoffs among the different specialty organizations involved in the project; (3) *lookahead planning* which breaks down the tasks from processes to operations, identifies constraints, and assigns responsibilities to make tasks ready; and (4) *weekly work planning* during which reliable promises and commitments to execute the work are made [7, 8, 9].

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Of the LPS different phases, lookahead planning plays a critical role as it bridges between master and phase scheduling from one side and weekly work planning from the other side. It serves to break down tasks from the process level employed in the master and phase schedules into the operation level of detail that is needed for commitment. Moreover, as previously mentioned, tasks are made ready during this phase after identification and removal of different constraints [7, 9]. These constraints could subsume design or construction related information, equipment and machinery, labor, space, predecessor activities, weather conditions, and others [10, 11]. Thus, the reliability of the construction workflow can increase when tasks are made ready for execution just on time.

In the LPS, the reliability of the construction workflow is generally measured using the metric "Percent Plan Complete" denoted as PPC. PPC measures the percentage of tasks completed at the end of a fixed time interval relative to those that were planned at the beginning of this interval [7, 8]. As for measuring the performance of the lookahead planning phase, two metrics "tasks Anticipated" (TA) and "tasks made ready" (TMR) are used. TA measures the effectiveness of the lookahead planning in anticipating the tasks that are going to be executed in the future. On the other hand, TMR assess the performance of the lookahead planning in identifying and removing the different types of constraints, previously mentioned, for tasks to be ready for execution. TMR denoted as TMR (i, j) refers to the percentage of tasks anticipated on the lookahead plan i weeks ahead of the execution week j [12, 13].

Several studies have targeted the make-ready process [14, 15, 16]. In fact, one of the studies has explored the impact of the make-ready process on PPC. The percent of constraints removed relative to all constraints identified on the lookahead plan one week before execution was measured using a metric called "Percent of Constraint Removal" denoted as PCR_1. A strong correlation between PCR_1 and PPC was found in three case study projects [14, 15]. Other studies have shown that productivity increases with increased reliability of workflow which is reflected as a higher PPC [6]. However, there are no detailed studies addressing: (1) the planning actions followed; (2) the parameters that affect the make-ready process; and (3) the effect of modifying these parameters on the reliability of planning, measured in PPC and schedule performance, measured in project duration [13].

In acknowledgement of the need to explore such aspects, this paper aims at studying the relation between TMR, PPC, and project duration on construction projects by simulating real project conditions. The behaviours of TMR, PPC, and project duration are studied under various conditions enhancing the understanding of the effect of making tasks ready on planning reliability and project duration. For these purposes, a theoretical framework is developed for the make-ready process within lookahead planning. This is accomplished through building a simulation model for the make-ready process and testing different scenarios by varying different parameters. This will be further expanded in the methodology section below.

2. Methodology

The research method includes 4 main stages: (1) developing a conceptual model for weekly work planning starting form a lookahead schedule, (2) building the corresponding mathematical depiction of system into a computer simulation model; (3) designing an experiment to understand the impact of TMR on project duration while varying input parameters and measuring the output variables as shown in table 1; and (4) analyzing the results. Once the model was set and verified, it was used as a laboratory for testing various scenarios and project conditions.

2.1. *Weekly work planning process*

The lookahead process as it progresses from six weeks ahead of execution until the week of execution was modeled as follows.

(1) *6 to 3 weeks ahead of execution*: Tasks obtained from the phase or master schedule are added on the six weeks lookahead plan. During this period, gross constraints, which relate to phases and processes, are identified and removed. These constraints subsume, for example, design and material information which necessitate long lead time to be removed [5, 9]. Tasks are then broken down into processes and operations.

(2) *2 weeks ahead of execution:* Tasks are continuously broken down until they match the level of detail necessary for production at the weekly work plan level. During this week, specific constraints, relating to specific tasks or operations, are identified and then removed in order to make tasks ready. These constraints include prerequisite tasks, material, space, information, and other resources.

(3) *1 week ahead of execution:* At this stage, the process of *pulling* and *screening* of tasks is conducted. *Pulling* helps in identifying the tasks that should be made ready based on the actual site demand. As for *screening*, it helps determine the actions needed in order to remove the different types of constraints, previously discussed. This prevents commitment to tasks that cannot be made ready [7, 9]. At the end of this process, tasks are divided into two categories: tasks that are made Ready (R % of all) and those that are Not-Ready (1-R % of all). Out of the

Not-Ready tasks, a certain ratio P has a probability of having the constraints removed. These tasks, which are not Ready but can be made Ready (denoted as CMR) are advanced to the weekly work plan (WWP). The remaining portion (1-P) cannot be made Ready (CNMR) and, thus, is not advanced to the WWP. However, this portion will undergo the same analysis in the following lookahead planning cycle.

It should be noted that any task undergoes a process of *shielding* before joining the WWP. In this process, tasks are tested against five quality criteria including definition, soundness, sequence, size, and learning. Any task must be well defined, constraint-free, in a proper sequence, and adequately sized to match capacity and must allow learning for continuous improvement. By ensuring that only such tasks are moved to the WWP, the shielding process protects downstream tasks from uncertainties of upstream tasks and, thus, ameliorates plan reliability [12, 17].

Excess tasks that are ready but not critical are added to the workable backlog and are executed in case of extra available capacity. Some tasks other than those pebbles that were broken at the beginning of this cycle are added at the last moment to the WWP. These tasks (denoted as New) add more complexity to the planning process and might be hard to be made ready just in time for completion.

(4) *During the execution week:* Tasks that are actually unconstrained (denoted as Ready Ready-RR) and constrained tasks that were made ready during execution are successfully executed. On the other hand, some tasks that were perceived as ready before and they were actually not ready or got constrained during execution fail to be executed. These tasks are called “not quite ready” and denoted as 1-RR. As for the CMR tasks, coordinated effort must be made in order to remove their constraints and execute them. These tasks are denoted as NR while those that cannot be made ready are denoted as 1-NR. Regarding the New tasks, a portion of them denoted as N will be made ready and executed while the second portion denoted as 1-N cannot be made ready or executed.

At the end of this week, Percent Plan Complete (PPC) is calculated by dividing the number of tasks executed by the number of those planned. TMR is calculated by dividing the Made Ready task at WK0 (execution week) that have survived from WK2 (two weeks ahead of execution) over the total number of tasks on WK2. This lookahead planning process is repeated until all the tasks are executed denoting the end of the project.

Table 16 below summarizes the parameters used as well as their corresponding values.

Table 16. Test Parameters and Values

Parameters	Description	Values
Rocks	The number of tasks at the level of detail of processes in the project.	2,080
Rocks to pebbles	Ratio of the number of tasks at the lookahead level that an activity gets broken into.	Randomly selected from {2, 3, 4}
R	Percentage of tasks that are made ready during WK1.	{0.1, 0.3, 0.5, 0.7, 0.9, 1}
RR	Percentage of *Ready* tasks that are actually ready or unconstrained.	{0.1, 0.3, 0.5, 0.7, 0.9, 1}
P	Percentage of tasks that are *Not-Ready* but have a chance to become ready some time prior to their scheduled execution.	{0.1, 0.3, 0.5, 0.7, 0.9, 1}
NR	Percentage of *Not-Ready* tasks that will be made ready during the execution week.	{0.1, 0.3, 0.5, 0.7, 0.9, 1}
N	Percentage of *New* tasks made ready during the execution week.	{0.1, 0.3, 0.5, 0.7, 0.9, 1}
NBR	Ratio of *New* tasks at WWP to *tasks* at the end of *WK2*.	{0.1, 0.3, 0.5, 0.7, 0.9, 1}
New	Number of tasks added to the WWP at the last moment without undergoing lookahead planning process.	NBR*Broken Pebbles
Total number of runs	It is equivalent to all the possible combinations of values that the parameters can take which is equal to 6^6, given that each of the 6 parameter can take 6 different values {0.1, 0.3, 0.5, 0.7, 0.9, 1}.	46,656

2.2. *Simulation Model and Experiment*

The conceptual model was then built into a discrete event simulation model in Any Logic 7 (university edition, educational version). To test the relationship between TMR, PPC, and project duration, an experiment was designed to find the possible impacts on PPC and project duration when varying TMR. The experiment tests the impact of various combinations of parameters. To vary TMR, the governing parameters R, RR, P, NR, New, and

NBR are varied in almost all combinations. The resulting TMR, PPC, and project duration are recorded and analyzed as per the parameters shown in table 1. This experiment can resemble almost any type of project. Having six parameters taking on six different possible values, there are 46, 656 possible combinations studied. Results are shown in the next section.

3. Results and Discussion

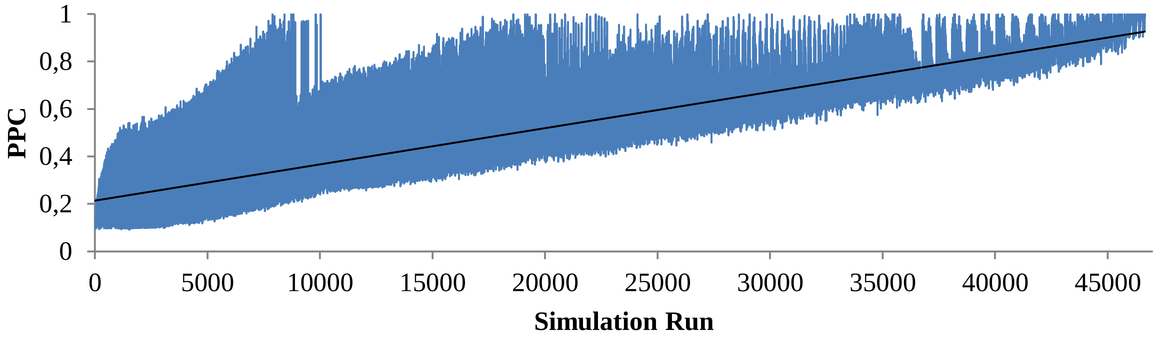
The experiment's objective is try all different combinations of the parameters shown in Table 1 and then analyse the resulting TMR, PPC and Project Duration. These results are shown in Figure 1. For each graph, the x-axis corresponds to the run number where each run consists of a different scenario defined by a certain combination of the project parameters R, RR, P, NR, N and NBR. It is important to note that although N and NBR have no major effect on TMR, they were included as part of the experiment's parameters due to their effect on PPC and project duration.

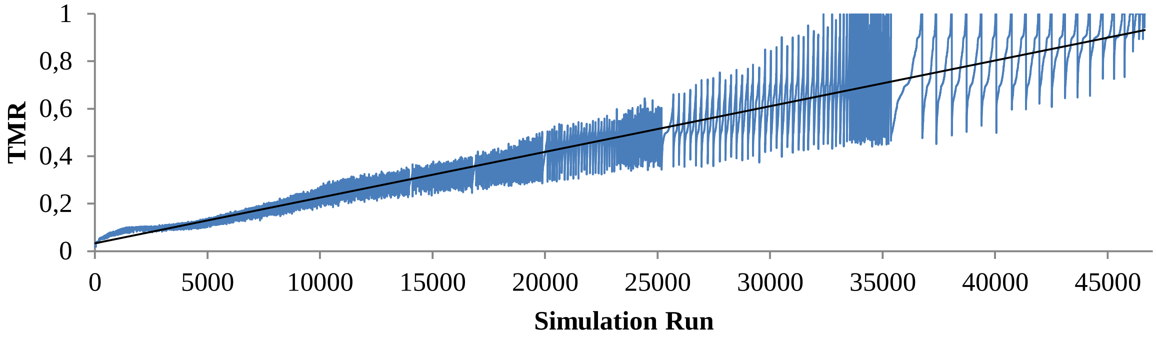
In order to get a clearer view of the results, the different scenarios are sorted according to increasing project duration. Linear trend lines are also added to both TMR and PPC to have a better idea of these results' overall trend. Moreover, the project duration's y-axis is fixed at 100 weeks even though some runs reached durations over 100. Adding these relatively few high values would have negatively altered the graph's scale, resulting in an insignificant representation of results.

The results show that as project duration decreases both PPC and TMR tend to increase as a general trend. It is also worth mentioning that the project duration's decreasing pattern is not linear but rather logarithmic which means that when PPC and TMR are low, working on increasing their values can greatly improve project performance. However, after a certain point, improving project duration becomes more challenging since the rate of improvement becomes less significant. In fact, a jump of TMR from 0.035 to 0.25 resulted in a total duration reduction of over 40 weeks whereas a jump of TMR from 0.25 to values close to 1 resulted in a reduction slightly greater than 10 weeks. This raises questions on the economic sense of increasing TMR beyond a certain threshold.

When the results are evaluated on a scenario by scenario basis, more interesting inferences can be made, especially regarding PPC. The PPC graph reveals that very high values are reached (values close to 1) for project durations as high as 77 weeks which is 20 weeks greater than the lowest possible duration. The same cannot be said about TMR since there are no instances where a high project duration is coupled with a high TMR. This is the case because PPC does not take into account cannot be made ready (CNMR) tasks unlike TMR. So, a high PPC coupled with a long duration simply means that the project is under-committing by having a high number of cannot be made ready tasks even though all the ready and can be made ready activities are being executed at a high rate.

Although the TMR trend is closer to that of project duration than PPC, it is still not completely linear, having a range of value for given project durations. This range is due to the presence of *New* tasks which are not part of the original weekly work plan. A high number of *New* tasks coupled with a low N (making them ready) will negatively affect project duration without affecting TMR since the latter does not take *New* into account. Similarly, a high number of *New* activities and a high N would positively impact project duration without affecting TMR. A high N is a sign of an agile project team who can work fast on removing constraints for tasks that emerge at the last moment. Despite this range of TMR resulting from variations in New and N, TMR still proves to be a better and more reliable indicator of project duration than PPC.





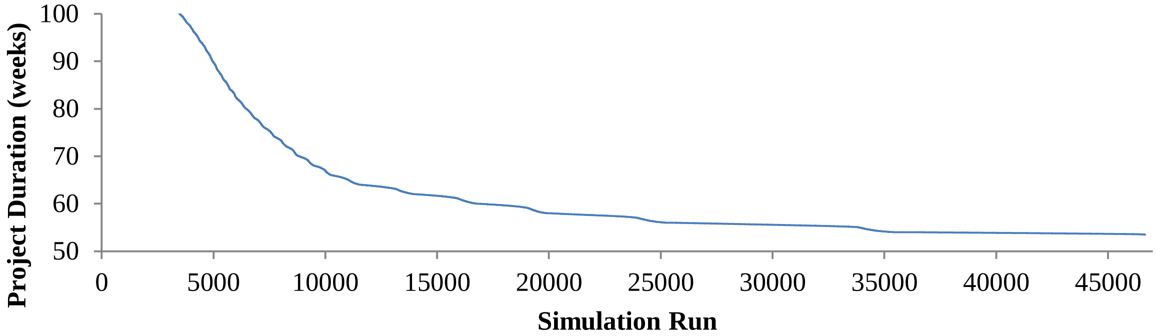


Figure 17. Results for TMR, PPC, and Project Duration

4. Conclusions

This study presents results from simulation experiments conducted to investigate the relationship between TMR, PPC, and project duration. The results confirm the importance of the make-ready process and how constraint removal can influence project duration. The practical impact of this finding suggests that improving the team's ability to perform sound lookahead planning, design operations to match load and capacity, and remove constraints before and during execution can have a profound impact on improving plan reliability measured by PPC and overall project duration.

As TMR increases, the project duration decreases in a clear fashion. However, the decrease in project duration flattens and becomes asymptotic for higher values of TMR. When New is high, the impact of TMR on project duration is shared with the impact of N. If TMR and N are high then project duration is at a minimum. A high N is a sign of an agile project team who can work fast on removing constraints for tasks that emerge at the last moment.

The results show that a high TMR can result in a reduced project duration but the same cannot be always said about PPC. A schedule with a high number of 'cannot be made ready' (CNMR) tasks can result in a high PPC but would most probably result in a long project duration. PPC can also be gamed by a project team on a real-life project to appear high by under committing.

In conclusion, TMR serves as a better indicator for project duration than PPC. The practical implications of this finding invites practitioners to put more focus on sound look ahead planning where future weekly work plans are studied early, operations are designed to match load and capacity, and constraints are successfully removed before and during execution. The fruits of this focus would show through improved plan reliability measured by PPC, a higher rate of constraint removal measured by TMR, and a reduced overall project duration resulting from executing more tasks on-time and enabling a timely start for more downstream tasks.

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Applying Political Apportionment to Pre-Allocate Float / Buffer Ownership

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Abstract

Float in project schedules can provide important protection for activities if delays occur. Traditionally, total float exists along noncritical paths and shared among these activities. This has given rise to the longstanding question of who owns float. However, by definition the critical path lacks the unique flexibility provided by float. This conundrum is newly addressed by explicitly assigning float from the project finish as a buffer. Another more specific question appears: If each critical activity is entitled to a portion, what should its share be to protect the project? And how well does it fulfill the criterion of fairness, since activities are typically performed by different companies? Political apportionment is an established area to fairly distribute parliamentary seats by the votes that representatives have received. It provides systematic quota calculation with rounding methods to give consistent integer results that consider the relative size, i.e. importance, of competing participants. Inspired by apportionment, this research adapts a methodology to solve the problem of optimizing float allocation. Its contribution to the body of knowledge is twofold: First, float allocation is integrated with various apportionment methods. Second, an index is created to compare their performance based on Monte Carlo simulation. This research thus transforms float from being a passive byproduct of schedules to an active asset with which project managers can reduce delays. It builds a foundation for future research on active float management.

Keywords: Critical path, float ownership, political apportionment, project float, schedule activities.

1. Introduction

Time performance is a crucial aspect in project management. Construction delay, which is defined as “an act or event that extends the time required to perform tasks under a contract” (Stumpf 2000, p. 32), is the main contributor to bad time performance suffering the construction industry (Birgonul *et al*. 2015). For example, Mahamid *et al*. (2012) studied road construction firms in Palestine. The results showed that 75% of contractors had experienced 10-30% as a delay magnitude, 20% even indicated that their delay magnitude was 30-50%. A statistical analysis of road projects in Indiana found 1655 of 1862 (89%) delayed (Bhargava *et al*. 2010). Menches and Hanna (2006) studied electrical projects in the U.S. Among 60 responses, 53 projects (88%) were delayed. While an even more abundant literature exists that contain similar alarming delay statistics, for brevity only a selection of them has been listed here.

Reasons for poor time performance are twofold: 1. An as-planned schedule that is too tight; or 2. the as-built time performance is indeed poor. The former is beyond the scope of this paper and will be covered by future research. But for the latter, buffers and total float (TF) are the two basic protection mechanisms that provide “a cushion or shield against the negative impact of disruptions and variability” (Russell *et al.* 2014, p. 2). Scholars of the critical path method (CPM) have emphasized the classic ‘*who owns float*’ problem, where TF “represents the length of time an activity’s finish date may be delayed without affecting the completion date of the entire project” (de la Garza and Vorster 1990, p. 716). “Total float is a by-product of critical-path-method calculations” and should be traded as a commodity between project participants (*ibid.*). Time performance is directly related to contractual reward / penalty schemes, i.e. bonuses or liquidated damages. Thus how to fairly allocate such float is important for all participants.

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2. Literature Review

2.1. *Float / Buffer Allocation*

Float and buffers "are two closely related phenomena that only differ in whether they are intentional" (Lucko *et al*. 2016, p. 2). Both of them can be used to protect the project finish from delays. Yet activities in a project schedule are conducted by various participants (owner, general contractor (GC), or subcontractors). "The complexity of distributing the float among these parties stems from the fact that the TF belongs to the path, not to the activity, and there can be many project parties on the same path" (Al-Gahtani 2009, p. 88). So does the buffer. Previous research can be grouped as participant-oriented versus activity-oriented. The former deals with float in terms of whether the owner or GC owns it, and is "based on the basic concept that the party who has the greatest risk in a project should be entitled to float ownership" (Al-Gahtani 2009, p. 88). But its problem is that a contractual risk factor is defined as a constant percentage, but it "should be changed for each activity based on the contract terms" (*ibid.*, p. 92). As a result, a solution for participant ownership would still have to subdivide contract risk factors by what actual work they self-perform (owner) or perform (GC). For activity-oriented, Pasiphol (1994, p. 94) advocated to "distribute more total float to activities requiring more time to be completed". But such research was based upon a fixed as-planned schedule without considering any probabilistically distributed durations, and its concept 'float in proportion to duration' would require mathematical analysis of its fairness. Inspiration is provided by political apportionment in Federal systems: For the example of the E.U. (Kirsch 2007, Pöppe 2007), it was proven that assigning voting weight in proportion to the square root of the population n of each country will strike a perfect balance between 'one vote per country' that is proportional to n^0 versus 'one vote per person' that is proportional to n^1. An opportunity exists to adapt this successful approach to solve how to fairly allocate a buffer or float specifically to the critical activities.

Critical Chain Project Management (CCPM) was developed to ensure a timely project finish by inserting limited buffers and imposing a general sense of urgency. It protects the time performance of critical activities with a single project buffer (PB) at the end of the critical chain. It analogously protects noncritical activities with feeding buffers (FB) at the ends of non-critical chains (Herroelen and Leus 2001), i.e. merges of side paths. If an activity is delayed, the FB will act as a local cushion or the PB as a global cushion. "But this approach radically cuts activity durations, assuming that they harbor individual float, returns half of it as a single large end buffer [PB], and then accepts that said 'block' is consumed fully without tracking by whom" (Lucko and Su 2016, p. 1). The CCPM has drawbacks, notably that (a) aggressively cutting their initially planned durations in half, then aggregating half of the summed cuts back into PB (Goldratt 1997) is regrettably not founded on any scientific approach or real-world data, (b) while it seeks to protect its critical chain (akin to critical path), it does not explicitly allocate PB, which can cause legal disputes over delay claims, and (c) it is fundamentally unfair, because it espouses a 'first-come, first-serve' tactic.

Table 1 compares float / buffer ownership approaches from the literature (e.g. Al-Gahtani 2006, Al-Gahtani and Mohan 2007, Arditi and Pattanakitchamroon 2006, Prateapusanond 2003, Pasiphol 1994, de la Garza *et al.* 1991, Householder and Rutland 1990, Ponce de Leon 1986). Problematically, they either contradict each other (Al-Gahtani 2009), (owner versus contractor approach), or leave unclear how to fair split should be achieved (project approach).

While some approaches suffer from an unclear split between owner and GC, others are activity-oriented and focus on subcontractors who perform the actual work. Some require *ex post* analysis (bar and day-by-day approaches). But only the total risk approach provides an explicit percentage of TF ownership *a priori*. Such PB/FB or TF approaches have a similar time-related object – buffer or float. As has been mentioned before, their difference is that the former is intentionally imposed by the CCPM scheduler, while the latter is calculated as an artifact of the activity durations and links in the schedule. But except for CCPM, which has the aforementioned drawbacks, all of these ownership approaches can only handle TF and do not protect the critical path, which by definition urgently lacks protection.

Yet extra 'contract float' (*CF*) exists between the as-planned project finish and the contract due date (O'Brien and Plotnick 2009, Keane and Caletka 2008). This paper assumes that uninflated activity durations that are based purely on a realistic productivity are known to calculate the 'raw' project finish. This *CF* is the only time contingency that is available specifically to critical activities. But it currently lacks an explicit allocation method. Therefore this research poses a question: *How should CF be use optimally to protect the critical path, i.e. how should it be allocated fairly?*

Table 1: Comparison of Float / Buffer Ownership Approaches

Approach	Critical	Non-Critical	Participant	Allocation
Owner Ownership	N/A	TF	Owner	100%
Contractor Ownership	N/A	TF	GC	100%
Project Approach	N/A	TF	Owner / GC	x% / x% *
Equal Proportion	N/A	TF	Owner / GC	50% / 50%
Bar Approach	N/A	TF	Activity	Consume TF, then excuse
Contract Assigns Risk	N/A	TF	Owner / GC	x% / x% *
Path Distribution	N/A	TF	Activity	Based on duration
Day-by-Day Approach	N/A	TF	Activity	Track TF changes
Commodity Approach	N/A	TF	GC	Trade TF for cash
Total Risk Approach	N/A	TF	Activity	TF proportion to risk
CCPM Method	PB	FB	Activity	First-come, first-serve

** Undefined in case law. Note: PB (FB) at end of (non)critical chain; TF shared along noncritical path.*

2.2. *Political Apportionment*

Political apportionment deals with the issue that "electoral votes must be translated into specific seat allocations… [t]he seat allocations are of course integer numbers" (Schuster *et al*. 2003, p. 652). Suppose P total votes are given to n parties, with p_i votes for the i^{th} party, where $\sum p_i = P$. A total of N seats must be apportioned to these parties. Thus the party percentage is p_i / P. The exact allocation (often called fair share or quota) is $q_i = N \cdot p_i / P$. But this value is not always the required integer, as fractional seats are impossible. Calculating seats from votes thus is adjusted, for which various apportionments have emerged, including largest remainder (LR) and divisor methods (e.g. Jefferson, Adams, Huntington-Hill, etc.). The LR first rounds quotas down to the nearest integer ($\lfloor q_i \rfloor$). The difference between their sum $\sum\lfloor q_i \rfloor$ and N are the leftover seats. Next it takes the party with the largest remainder, $\max(q_i - \lfloor q_i \rfloor)$, and assigns one leftover seat. If seats are still left, assigns one to the second largest remainder, andsoforth. But LR suffers from the so-called 'Alabama Paradox' that *increasing* N by a day may counterintuitively cause the smallest party to suddenly *lose* a seat, because rounding the revised values may give a slightly different integer allocation to all parties (Wiseman 2001). The latter includes several methods that seek a proper divisor λ. The Greatest Divisor (GD) and Smallest Divisor (SD) methods differ only in that the former rounds down the quota divided by λ, but the latter rounds up. Geometric Mean (GM), Harmonic Mean (HM), and Arithmetic Mean (AM) use different means: Both GM and HM round down quotas $f_i = \lfloor q_i \rfloor$ and calculate the mean of f_i and $f_i + 1$; AM takes the arithmetic mean, but different from the other two mean methods it rounds to the nearest integer, instead of always rounding down. Then GM and HM compare the quota with the mean to judge if f_i and $f_i + 1$ should be used; AM just rounds the operant to the nearest integer. Note that the quota q_i in GM and HM may not yet equal N. In such case, q_i is adjusted through a divisor. Divisor methods require time-consuming iterations that can be automated with computer programming.

Analogies exist between political apportionment and float / buffer pre-allocation (Lucko and Su 2016): 1. The goal is to fairly apportion an limited asset; 2. seats or float / buffer represent a power of entitlement (party in politics, activity in schedule); 3. results must be integers (seats or time unit like workdays) whose sum must equal the total amount that is available. Therefore it is feasible to newly apply political apportionment methods to float / buffer pre-allocation. Two **Research Objectives** are set to address the **Research Question** of optimally pre-allocating the CF:

- Inspired by political apportionment, create a float pre-allocation method whose quota is based upon activity duration with variable exponents to evaluate the protective ability in proportion to n^0, the square root $n^{0.5}$, and n^1.
- Create a measurement index to evaluate the performance of Monte Carlo simulations of the LR and AM methods.

3. Methodology

Applying political apportionment to pre-allocating float / buffer to each critical activity has these steps: First, inputs of activity name, duration D_i, and sequence are used in CPM to identify critical activities. Second, calculate D_i to the power of n akin to 'votes' (p_i) for each critical activity. Third, incrementally increase the float / buffer akin to 'total seats' (N) and select an apportionment method. The output is an allocation of float / buffer like apportioning seats to each party (s_i). Fourth, run a Monte Carlo simulation L times to generate randomized as-built schedules with delays from given probability distributions for each activity. Fifth, calculate any overrun of the fixed duration D_i as an integer time, e.g. $\lceil d_i - D_i \rceil$ and compare it with the allocated float (s_i). Sixth, for each critical activity calculate the discrete count of overruns out of L times, and the overrun period $(d_i - D_i) - s_i$. Seventh, plot the simulation results of discrete count and overrun period over the incrementally increased *CF*. They are expected to be decreasing stepped 2D profiles of counts over time (discrete performance) and period over time (continuous performance). Eighth, calculate statistical indices for each profile to quantify their protective ability against delays: The arithmetic mean for each profile between the times when the profile begins to decrease and when it reaches zero (and is thus saturated with float so that delays can be fully mitigated). Then calculate minimum, mean, maximum, and standard deviation of these averages. Finally, after running simulations for all apportionment methods and all exponents, select the best combination of method and *n*, which should have the smallest mean and standard deviation for its discrete and continuous performances. This new methodology has integrated the float pre-allocation with political apportionment and fulfills **Research Objective 1**. Critical path changes are not examined, but will be addressed by future research.

4. Validation

A validation schedule is selected from the Project Scheduling Problem Library (PSPLIB, Kolisch and Sprecher 1996). It has 30 activities plus one dummy start and finish. The authors have developed a computer program that can automatically visualize the network per Figure 1. Since the PSPLIB data only include the sequence of activities and fixed durations, this paper adds a probability distribution for activity durations. Users can specify any type of distribution. Here, 90% and 150% of the fixed mode is used as the lower and upper limits of a triangular distribution. Note that fractional overruns are rounded up to count them as integer days, the basic time unit that is assumed herein. While this example only contains Finish-to-Start links, the computer program and method can handle any link type.

The optimistic, most likely (mode), and pessimistic project durations are 34.2, 38, and 57. Theoretically the most float that should be required is the difference between the pessimistic and the optimistic duration, which is 22.8 days.

4.1. *Simulation Outputs*

Figures 2 and 3 present the count and period profiles for the three exponent cases with two methods (LR and AM) after 100 simulation runs. Note that all profiles in the count figures start below 100 counts, because some randomly sampled durations from the triangular distribution are shorter than the mode, so that no overrun occurs. As expected, all profiles decrease with increasing *CF* – the more float is allocated, the more each activity receives and the less often they overrun. The upper three plots in Figure 2 are the count profiles for exponents 0.0, 0.5, and 1.0 and LR, while the lower ones are the period profiles. In terms of the maximum of the averages of decreasing range, the $n = 1.0$ case provides the optimum (least) value of 13, compared to 19 and 15.5, respectively. But in terms of the mean of the averages, $n = 0.5$ is the best (2.84, compared to 3.05 and 3.10. Thus the group trend shows that the square root approach is better. Interestingly the Alabama Paradox is seen in the dashed circles when *CF* changes from 18 to 19 for $n = 1.0$; a peak shows how a short activity briefly receives less float, is more vulnerable, and may incur overruns.

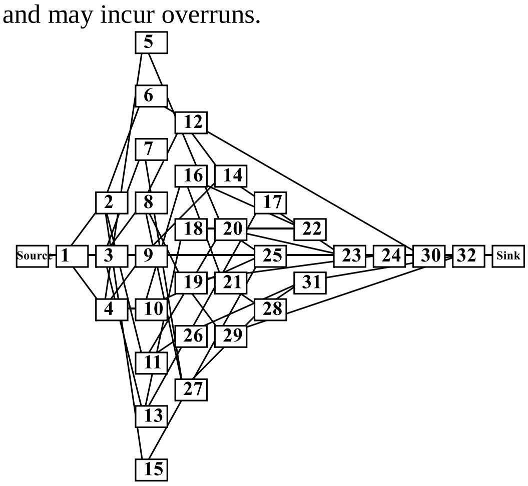

Figure 1: Network of the J30_1 Schedule

Figure 3 shows the count and period plots for AM with the same exponents. Characteristics similar to LR are seen. The Alabama Paradox disappears, because of the different apportionment; AM requires searching for a proper divisor iteratively. But different from political voting, some critical activities may have exactly the same mode duration and thus share the same quota. If so, the divisor method cannot provide a solution for certain *CF* values. Two adjustments are therefore made to gain a continuous profile:

- An increment (0.001) is added to (or deducted from) activities with the same initial duration, so that they have different quotas. It does not alter the solution, as it does not affect the duration structure within the schedule, but distinguishes their power;
- If no optimal solution can be found for a specific *CF*, then the solution from the previous smaller *CF* is kept. This ensures that at least such a suboptimum solution is provided as valid output.

Comparing the statistics for the outputs of Figure 3, the group trend again indicates that $n = 0.5$ is the most efficient way (the mean of averages is 2.74, compared to 2.90 and 3.06) to pre-allocate float to protect the critical path from delays. Table 3 lists all results numerically (the minima are omitted for brevity). Its best combination is highlighted in bold. Interestingly, the results for n = 0.5 and n = 1.0 tend to be closer together. This is because pre-allocating the same float (n = 0.0) ignores any differences among activities. The best combination is AM and n = 0.5.

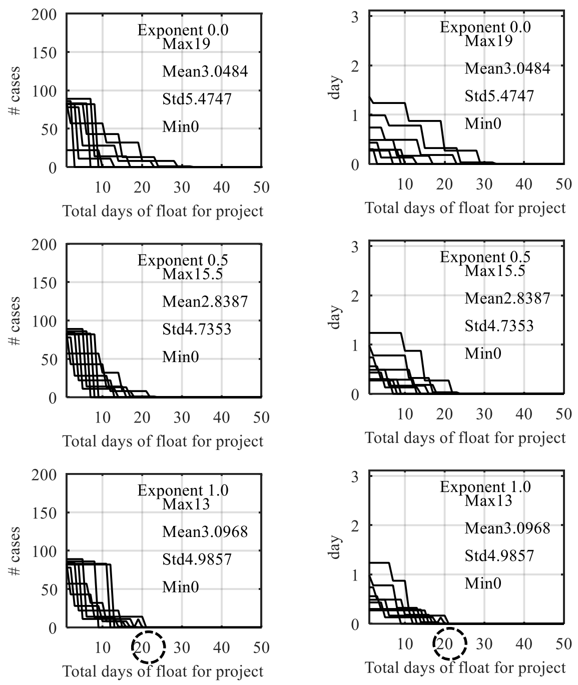

Figure 2: Count and Period Plots of Largest Remainder Method Simulation

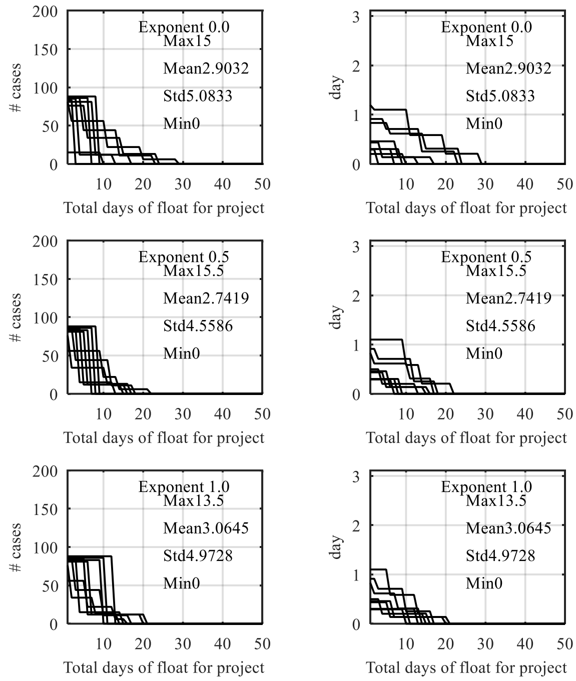

Figure 3: Count and Period Plot of Arithmetic Mean Method Simulation

4.2. *Discussion*

Comparing the statistical metrics of Table 3 has revealed that exponent n = 0.5 of the mode duration and the AM method should be selected when using the quota to determine the optimum float pre-allocation. In this combination, the apportionment method gives the smallest mean of the averages. This means that in most cases of the simulation the critical activities are ideally protected by their allocated integer part of *CF*. Both counts and periods of overrun confirm this observation. Theoretically, the method of using n = 0.5 should be fairer than 0.0 and 1.0. Exponent 0.0 unfairly favors short activities, because all critical activities have the same quota. Here short ones stop overrunning quickly and any extra allocated float is wasted, because their need is also small. Conversely, only a high value of *CF* would eventually saturated long ones. Such behavior relies on the assumption that risk is approximately proportional to duration, which has been used as a proxy for it. If shorter activities are riskier for some reason (Al-Gahtani 2006), then the model should not use duration, as has been described here, but a direct numerical value of risk for its quotas.

Table 3: Comparison of Apportionment Methods

Exponent	0.0			0.5			1.0		
Method	Max	Mean	Std.	Max	Mean	Std.	Max	Mean	Std.
Largest Remainder	19	3.0484	5.4747	15.5	2.8387	4.7353	13	3.0968	4.9857
Arithmetic Mean	15	2.9032	5.0833	15.5	**2.7419**	**4.5586**	13.5	3.0645	4.9728

The opposite happens for exponent 1.0, which strongly (directly proportionally) favors long activities. Any short ones are deprived of power to receive enough float and some may even never receive any. Note that the difference between durations among critical activities is a non-negligible factor, because it strongly affects how quotas are distributed. For example, a group of critical activities with very close durations {1, 2, 3, 4, 5}, and another with very diverse durations {1, 1, 1, 2, 10} might perform differently for n = 0.5. This exponent is not always the best option, but each specific schedule may have a customized optimum exponent. This notion is beyond the scope of this paper and is left for future research. Comparing the simulated performance of LR and AM fulfills **Research Objective 2**.

5. Conclusions

Existing float ownership literature has unfortunately only focused on distributing TF, while CCPM is allocating buffers to provide a time cushion at the end of each chain without any scientific underpinning. A method to explicitly pre-allocated CF to the critical path has been lacking. This paper therefore has provided a detailed new methodology that integrates political apportionment methods into float allocation to answer '*who should own the float and how much to given to each critical activity*?' Steps have included: 1. The CPM calculation of a fixed duration schedule to determine critical activities; 2. calculating a quota for each critical activity with different exponents (0.0, 0.5, and 1.0) and using various apportionment methods to obtain the float pre-allocation; 3. running Monte Carlo simulations to generate randomized schedules with a given probability distribution and comparing if the delay of critical activities overrun their allocated float or not by recording both overrun counts and periods. 4. plotting these results over the increasing amount of float, and determining the minimum, mean, maximum, and standard deviation of the average time when the profiles degrease. Validation by comparing results from simulating a PSPLIB schedule has shown that this method can select an ideal apportionment method and its exponent to provide optimum protection.

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Creative Construction Conference 2016

Cash Flow Multi-Criteria Analysis in Construction Projects

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Abstract

The tremendous economic challenges especially due by to the persistence of the financial crisis and the continuous decline of public investments in the last years have increased the financial risks faced by construction companies. With high capital expenditures and high level of competition in the market, the construction companies have to accept a large number of risks, which make them very vulnerable. In order to stay in the market, the construction companies often participate in tenders with prices increasingly smaller, making them vulnerable to the occurrence of unforeseen events that are inherent in any construction project. In the current political, economic, social and administrative situation, the most important vulnerability of the construction companies is the lack of liquidity at the level of the contracting authority, but especially at contractor level. This financial weakness leads to delays in the project implementation, in penalties for delay and lost opportunities, with direct effect on the health status of projects and organizations. Infrastructure construction projects are mainly base on FIDIC Conditions of Contract amended through special conditions by contracting authorities. This paper aims to examine the effect of conditions of contract relating to the financial relationship between the employer and the contractor and the influence that they have on the financial management exercised by contractor, providing them a practical tool for decision-making.

Keywords: Construction Project Cash Flow; FIDIC Conditions of Contract; Multi-Criterial Modelling; Project Financial Management

1. Introduction

Nowadays, the construction industry continues to face the effects of economic crisis. Even so, the actual funding systems are not encouraging the companies to improve their practices related to the project finance management. With high capital expenditures and high level of competition in the market, the construction companies have to accept a large number of risks, which make them very vulnerable. In order to stay in the market, the construction companies often participate in tenders with prices increasingly smaller, making them vulnerable to the occurrence of unforeseen events that are inherent in any construction project. In the last annual report ([1]), the president of FIDIC mentioned that “Unreasonable price competition in the awarding of engineering services is more frequent today than ever before”.

In the current political, economic, social and administrative situation, the most important vulnerability of the construction companies is the lack of liquidity at the level of the contracting authority, but especially at contractor level. This financial weakness leads to delays in the project implementation, in penalties for delay and lost opportunities, with direct effect on the health status of projects and organizations. The financial aspects of construction projects have always been a major challenge for construction companies, especially in the current economic climate.

The type of contract that is the foundation of the relationship between the parties has significant effects on the strategy that the construction company will adopt to achieve the objectives of cost, duration and profit.

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2. Financial Contractual Aspects

The large investments from EU founds or state budged involved in the infrastructure construction projects requires balanced, accepted and tested type of contracts In such case, FIDIC Conditions of Contract amended by particular conditions are the most used contracts. According to the statutes, FIDIC (International Federation of Consulting Engineers) is a federation of member associations that represent the consulting engineering industry globally ([2]), aiming to enhance the image of consulting engineers and to be the authority on issues relating to business practice.

Developed over 50 years as global standards, the FIDIC contracts are recognized and applied in many types of projects. They describes all aspects that govern the relationship between the contracting authority and the contractor: general provisions and actors of the contract, material labor, equipment and machinery, execution period, longer runtime, reception and during the defects notification, measurement works, changes, payments, termination, force majeure, insurance and claims, disputes and arbitration. The financial aspects are dealt with in Clause 14 - Contract Price and payments, which sets out the sequence of events typical payments. FIDIC Red Book "*Conditions of Contract for Construction of buildings and engineering works designed by the beneficiary*" [3] defines the sequence of typical events of payments: at the end of each month of the reporting period, the Contractor submit the Statement and the supporting documents to the Engineer. After its verification, if the Statement is accepted, the Engineer will issue in maximum 28 days the Interim Payment Certificate. The Employer shall pay to the Contractor the amount certified within 56 days after the Engineer receives the Statement and supporting documents. The Employer will make the final payment within 56 days after the Engineer issue the Final Payment Certificate. If we take into consideration that the minimum time needed by the Contractor to prepare the Statement and supporting documents is 7 to 10 days, the first Interim Payment Certificate (IPC) will be issued at 65 days after the Date of Commencement. Considering that issuing the invoice by the Contractor is 7 days, the first payment will be done at 100 days after the Date of Commencement.

However, this sequence in time may be distort if the contracting authorities modify the related sub-clauses, leading into larger time intervals of payment. In such case, the contractor will be forced to support a greater financial effort in order to complete the works. There are also other reasons the payment may be delayed: the contractor is not enough well organized and prepared to submit in time the Statement and supporting documents and the Engineer may issue with delay the Interim Payment Certificate. Such events will cause an increasing financial pressure for the contractor reflected in his cash flow, without taking into account the risk events and uncertainties typical for construction projects.

3. Practices in managing financial risks in the construction projects

Several studies were run on the construction project financial management practices, in relation to the contracting clauses, revealing the associated risks. In 2015, KPMG ran a global survey for the construction sector [4] focusing on the project management practices (planning, risk management, controls and governance, project performance and collaboration between the owner and contractor). The survey reveals that for 72% of awarding contracts cases, full competitive tenders took place. Despite some concerns about a lack of flexibility, the traditional design-bid-build approach remains one of the two most popular project delivery strategies, enabling the owner to work with various suppliers for different aspects of the project. One of the biggest concerns expressed by the survey participants is the accuracy of the estimated costs before committing to the project. The contingency model (for example, 10 percent model) is not useful in many cases to cover the risks. The type of contract which is the base of the relationship between the parties have significant effects on the strategy the construction company will take in order to achieve it purposes in terms of cost, duration and profit. The survey also reveals that most of the companies develop financial projections methods based on the deterministic estimation of project financial performance.

In [5], a practical cash flow analysis model is proposed, that can be applied by the construction companies mainly when decisions about portfolio structure are taken. The proposed model allows construction companies to predict not only when, but mostly what amount of money should be borrowed or obtain from internal or external sources and when and what amount of money should be return. Due to the high amount of money needed to perform the projects, it become reasonable to say that construction companies need a specialized bank and not commercial one, which will supports their financial needs.

4. Multi-criteria decision models for managing the construction projects

Most of the construction companies develop financial projections based on estimated financial performance of the projects, considering some basic assumptions, regarding the time frame (the financial projections cover the project implementation period plus three-five years after the project's completion), capital outlays and financing costs (they include any up-front and ongoing capital needs during the reference period), revenues associated with the project, expenses, capital structure. Net present value (NPV) and internal rate of return (IRR) are two of the most frequently used indicators for measuring the estimated financial performance of a project. When a project has a positive NPV, the project is financially appealing. If a project has a negative NPV, there is an expected negative cash flow or the project won't generate enough cash to cover inflation and the targeted return. IRR is the discount rate required to achieve a NPV of zero. The higher a project's IRR is, the more attractive the project is financially. Other indicators are used to complement the NPV and IRR, such as: payback period, weighted average cost of capital, terminal value. In [6] several key performance indicators for organizational structures in construction and real estate management were proposed. The traditional scheduling models were enriched ([7], [8]) in order for serve better to the project financial projections in a probabilistic approach. The semi-probabilistic simulation methods, mainly the Three Scenario Approach ([9], [10]) and the probabilistic ones ([11]) become more popular.

The complexity of the construction projects environment make very difficult to evaluate them using models with only one single parameter. Most of the models applied for assisting the financial decisions in the construction projects ([12], [13], [14]) are using multiple criteria, such as: economical conditions, market share, market prices, type of project, type of contract, project duration, the time allocated to prepare the tender, the company financial "health", the need to win the tender, the available resources, the estimated price, the available technologies and so on.

5. A proposed approach of multi-criteria analysis

Due to the adverse economic conditions, the contractor decisions are based taking into account his financial capacity to support the project, in direct relation with the incomes. The proposed model consider that different type of construction projects lead to specific shape patterns of the contract price distributed on time. The aim of analysis is to quantify the contractor potential financial effort due to the variation of several parameters: project duration, the date of commencement, the time interval for the invoice payment and the date of issuing of the Statement and supporting documents.

Three real projects of road construction, based on FIDIC Red Book Contract clauses were analyze. The first project represents the rehabilitation of a section of national road length of 38.27 Km, the second project aimed the establishment of a by-pass (76.25 km in length) and the third one dealt with the consolidation of a section of national road length of 7.2 Km. A number of 174 cash different cash flow patterns were developed and analyzed.

The contract price monthly distribution for each project is presented in figure 1, 2 and 3.

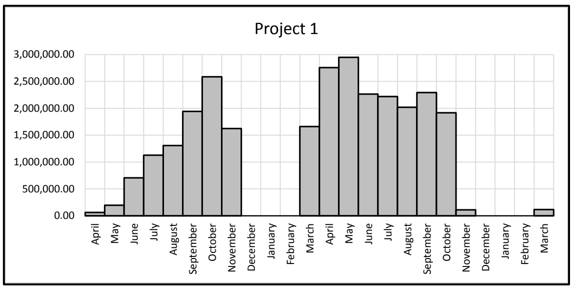

Figure 1 Contract price monthly distribution for Project 1

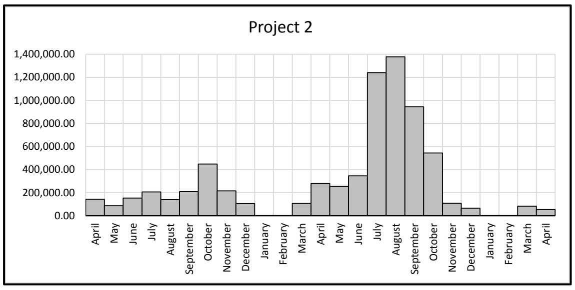

Figure 2 Contract price monthly distribution for Project 2

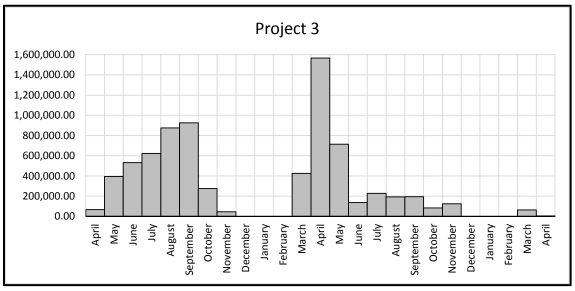

Figure 3 Contract price monthly distribution for Project 3

The following computation hypotheses were considered in the cash flow analyze:

- The payments will be made considering only the General Conditions of Contract;
- The effect of the advance payment and the guaranty for the advance payment was not taken into account;
- The depreciation, the bank taxes and commission were not taken into account;
- The Statement and supporting documents are prepared by the Contractor monthly, or for minimum 5% from the Contract Price.

In the cash flow analyze, the following parameter's variation were took into account:

- Construction project duration considering for one project the following durations: 16, 18, 20, 22 and 24 months;
- The date of commencement; the project schedule was develop so that the date of commencement of work to correspond the months from March to October;
- The time interval for the invoice payment considering the following payment terms: at 30 days, at 60 days and 90 days;
- The date of issuing of the Statement and supporting documents. Two cases were considered for the date of issuing the Statement: at 10 days and at 35 days after the reporting period

The project cash flow is consisted on the contractor costs with labor, materials, equipment and transport, other direct costs and overhead, profit and incomes from the payments, according with contractual clauses.
During the analyze we established the peak of the cash flow and its weight from the contract price for each scenario, identifying the best and the worst situation for each type of project.

5.1. *The influence of project duration*

The study of the influence of project duration was made on Project 3 – road consolidation of a section of 7.200 km of a National Road, considering the variation of duration between 16 to 24 months. The project cash flow was developed taking into account the payment of invoices on 30, 60 and 90 days, and the Statement and supporting documents are issued at 35 days after the reporting period. Considering that the date of commencement vary from March to October, there were retained the maximum and minimum weights of the peak of cash flow. As results, we obtained the domain of cash flow peak weight from the contract price considering the variation of duration (figure 4).

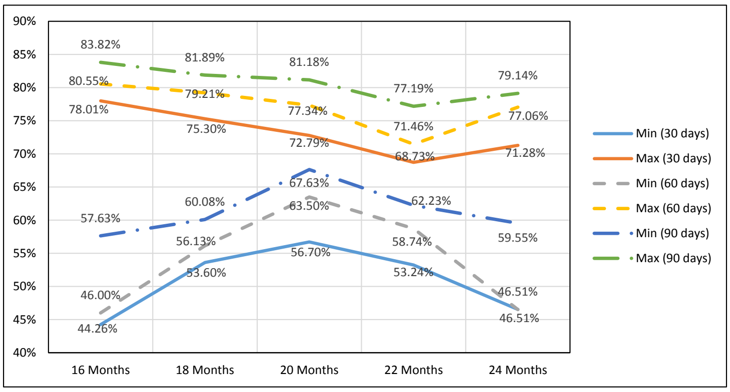

Figure 4 The variation of cash flow peak weight from the contract price for different project durations

Analyzing the results, we can find that for this type of construction project, the minimum weight of cash flow peak is obtained for 24 months duration, due to the distribution of the contract price on a higher duration. For this duration, the cash flow peak weight from the contract price vary from 46.5% to 79% depending on the date of commencement and the interval for payment. The contractor financial effort will be as higher as the delay of payment will be higher.

5.2. *The influence of date of commencement*

In order to emphasize the influence of the date of commencement on the contractor financial support, several hypothesis were took into consideration:

- All three projects have the duration of 24 months;
- The Statements and the supporting documents are submitted at 35 days;
- The payments is made at 30, 60 and 90 days.

In the case of Project 1 - rehabilitation of a section of 38.27 km of a National Road, the cash flow peak weight from the contract price vary from 41% to 69% depending the date of commencement and the interval for payment (figure 5). The best dates of commencement are in March and April, while the worst are in August, September and October.

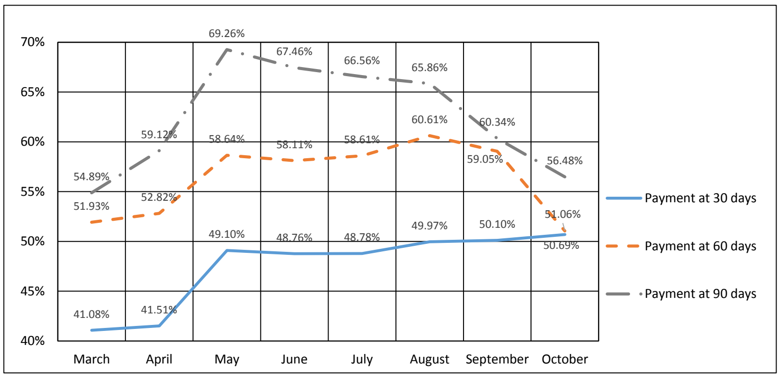

Figure 5 The variation of cash flow peak weight from the contract price for Project 1

For the Project 2 - the construction of a by-pass of 7.625 km, the cash flow peak weight from the contract price vary from 50% to 70% depending the date of commencement and the interval for payment (figure 6). The best date of commencement is in July, while the worst is in April.

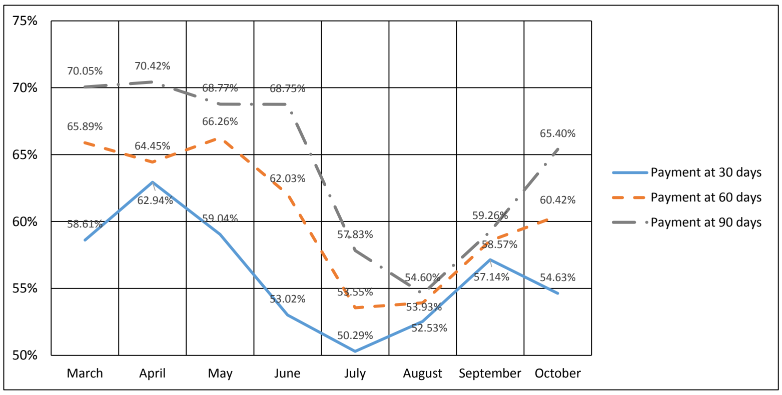

Figure 6 The variation of cash flow peak weight from the contract price for Project 2

In the case of Project 3 - the consolidation of a section of 7.200 km of a National Road, the cash flow peak weight from the contract price vary from 39% to 63% depending the date of commencement and the interval for payment (figure 7). The best dates of commencement are in April, May and September, while the worst are in March, July and October.

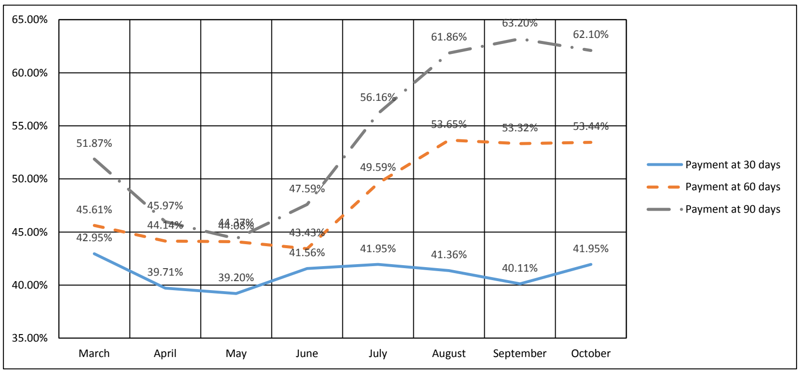

Figure 7 The variation of cash flow peak weight from the contract price for Project 3

5.3. *The influence of the time interval for the invoice payment*

Considering the same set of conditions, the contractor financial effort vary for the payment at 30 days between 44% - 71%, between 54% - 77% for the payment at 60 days, and between 64% - 79% the payment at 90 days, depending the type of project.

5.4. *The influence of the date of issuing of the Statement*

Although the timely issue of the Statement and supporting documents is in the interest of contractor, in practice it appears that this is not enough organized and prepared to develop the necessary documents. Issuing as soon as possible the Statement and supporting documents can reduce the contractor effort between 2% - 12% from the contract price, depending on the type of project and time interval for the invoice payment.

6. Conclusions

The results of this study suggest that different factors that can influence decisions both in the bid-tender stage, but especially in the implementation phase of infrastructure projects should be carefully considered by the construction companies. The specificity of works and applied technologies, the sequence of activities and resources involved, all are affecting the contract price distribution and is leading to major imbalances in the share of cash flow of the contract price. The construction companies have to adapt the terms of the contract by special conditions, along with the duration of the works, the time for invoice payment, the date of commencement and the time interval of issuance of Statements. The ideal conditions and homogeneous envisaged by the general contracting clauses required a significant effort of analyzing and understanding the dynamics problems of a financial nature faced by contractors after signing the contract without accounts but risk events and uncertainties that characterize fully these project categories. For this reason, the application of multi-criteria decision models can support the construction companies in managing better their projects.

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Initial Analysis, Planning and Calculation of Vertical Transportation in Construction

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Abstract

The tower crane is one of the major (key) equipment used in high-rise buildings construction. The main challenge encountered in the construction of high-rise buildings is the transportation of construction materials vertically and horizontally to the required or specific areas of the project. To tackle this challenge various equipment such as tower cranes, mobile cranes, hoists, etc., are used and out of all these equipment tower crane plays a vital role in the logistics of construction materials in the construction projects. Investors and General contractors very often use technical and commercial offers from the crane renting companies to make decisions concerning the number of cranes and period of engagement in the project. There is always a commercial and time risk involved to the Clients in the selection of cranes based on the offers from crane companies, as mostly these crane companies would try and sell what they have in their hand opposed to the most time and cost efficient options for the project. The main reason for that risky approach is a lack of standardized methodologies for the tower crane productivity calculation and decision-making on the selection of models for different proposed solutions by specialists. Identifying optimal number, location and duration of operations on the site are the major factors that can reduce the possibilities of the project outrun over the budgeted time and cost by increasing the productivity and lessen the time of construction. Often tower cranes operate with overlapping works zones, and under time, cost and labor constraints. Therefore, proper planning to be considered, while choosing a tower crane, based on different production parameters such as optimal space per worker, concrete production per crane or worker, lifting time, crane booms overlapping, health and safety measures, and crane operators well-being during the crane operation with maximum visibility to the work areas. In this paper, the methodologies for the number of crane calculation and their optimal positioning in three different construction phases are discussed - underground structures, above ground structure, façade, MEP and finishes work. CPM planning techniques (Primavera P6 software) is used for the proposed model, considering leveling and optimizing of crane usage. An actual case example is provided to demonstrate the planning model for the selection and positioning of tower cranes.

Keywords: construction, optimization, planning, tower crane

1. Introduction

A typical high-rise building construction involves lifting materials of different load size, type and weight, within the determined time with logistics, commercial, health & safety, administrative, programme and other constraints. For instance, let's consider concreting works, which are always in the critical path of high-rise construction projects, to which tower cranes are the most key logistic equipment which defines the programme certainty of these works. Therefore, tower crane needs to be planned appropriately. At present, planning for tower crane operations is mostly performed intuitively and based on experience (Hasan S. et al., 2010).

For any construction project, one of the most important documents are the general construction and logistics plans. General construction plan identifies number of cranes with their position. In authors experience, any delays during the preconstruction period (design, planning approvals, procurement) will be cascaded to the construction period and the project will require a mitigation strategy of all these delays within the construction period. In that case, the best option to reduce or mitigate delays within construction period is by increasing or optimizing number and position of cranes, along with the corrective measure and increasing of required resources (labors, material, other equipment etc.) will increase the production thus reducing the time and delay. In this paper author has analysed a case study from one of the large commercial project with possible suggestions for the improvement and optimization of tower cranes.

2. Methodology

The methodology outlined below was employed to determine necessary tower cranes and their optional location and time for a large commercial construction project. In practice, a tower crane is selected based on the maximum load needs to be lifted, size of the load, site layout, and the reach or capacity (Hasan S. et al, 2010).

Site organization with optimum resources to maximize production is the best way to reduce construction cost. Efficiency of concrete works mostly depend on:

- number, types and position of tower cranes;
- number, specialties of productive workers on site;
- quantity and type of formwork;
- availability of materials and supply ‘just in time’.

It is tough to calculate maximum production per worker, because of technological sequences, idle time, weather conditions, skills and physical condition of workers etc. (Hasan et al., 2010) calculated, based on production control, following data presented in the table 1:

process name	available time (min)	cycle time (min)	active (min)	idle (min)	% of utilization
inspection	480	13	429	51	89,38%
crane 1	480	15	255	225	53,13%
crane 2	480	15	240	240	50,00%
installation L1	480	20	340	140	70,83%
installation L2	480	20	320	160	66,67%

Table 1: Calculation of percentage of crane utilization (Hasan et al., 2010)

Based on percentage of utilization, standard construction method analysis and statistical data from three construction sites in Russia during different weather conditions, above results were calculated. It is found that maximum percentage of utilization per crane is only 53,13%. The above simple analysis was based on statistical data of monthly concrete poured (m^3) and number of skilled and unskilled labors assigned to concrete works (reinforcement, formworks and concreting works).

In general, tower crane utilization in construction job sites is estimated to be 50% to 80% (Hasan et al, 2013; Gillis & Telyas, 2013; Kay, 2001, Rosenfeld & Shapira, 1998). Reducing the crane lifting cycle or maximum utilization of tower crane not only increase the crane productivity but also helps in reduction of total project duration

The tower crane during its operation is the most key equipment in the logistics of the critical path activities. Saving in crane operations will have its impact on two major operational factors. First, saving in crane operation will shorten crane cycle time. Second, higher labor productivity is expected due to shortening of the crane operation.

Saving related to the crane operation cost can be divided into four categories:

1. Annual ownership cost: this is a cost of buying a crane throughout its useful life span;
2. Operation cost: included fuel, maintenance, license fees, and insurance;
3. Operator cost: this is salary of the crane operator;
4. Labor cost: cost of the laborer working directly with the crane.

Below, in the table 3, is presented crane operational time on site. Basically, due to the fact that tower cranes stay longer in the project and as their rental rates and mobilizing costs are high. Therefore it is not economical to rent a tower crane for the projects with longer project duration (Rosenfeld & Shapira, 1998; Sullivan et al., 2009).

For the tower cranes production calculation, it was used average production rates from author previous experience, presented in table 2:

- Optimal number of workers per crane during concrete works ≈ 70 workers;
- Winter productivity per worker ≈ 16 m^3/month (Russia);
- Summer productivity per worker ≈ 23 m^3/month (Russia);

From the previously defined data, average production per crane are:

- Production per crane underground (substructure) – 1200 m^3/crane/month;
- Production per crane above ground (superstructure) – 1500-1700 m^3/crane/month.

	jul	aug	sept	oct	nov	dec
Construction site 1 (commercial 185,000 m^3 of concrete)	8450	8920	9650	9790	6140	5920
	375	395	425	465	375	360
Construction site 2 (commercial 210,000 m^3 of concrete)	9230	9610	8420	8890	7290	7140
	390	400	385	395	440	420
Construction site 3 (commercial 320,000 m^3 of concrete)	12610	14100	14340	12220	11600	10650
	555	610	615	580	690	690

Table 2: Concrete production and number of workers on site

A concrete pouring plan is very essential to be defined and it has to be a part of project logistics plan, general construction plan and concrete works method statement. It can be prepared based on concrete quantities from schematic design which will form the basis for initial level 2 time programme. Concrete foundations and frame are always on critical path, and which are subjected to many constraints such as logistics, availability of concrete plants, traffic, pumps, tower cranes, etc. Tower cranes are primarily are used for the logistics of reinforcement, formwork, brickworks, concrete columns and concrete pouring, and for lifting other materials. In this paper two optimization steps are analyzed - determination of minimal number of tower cranes and optimizing location of tower cranes in order to minimize potential conflicts between tower cranes and other facilities. Each crane has his load chart that specifies lifting capacity. The maximum capacity is always obtained by the shortest crane's operating radius. (Irrizary and Karun, 2012).

For the proper planning of crane utilization, it is very important to define various phases of construction. Usually, underground and above ground construction are different from the point of view of tower cranes usage. In that case, the best option to reduce or mitigate delays within construction period is by increasing or optimizing number and position of cranes, along with the corrective measure and increasing of required resources (labors, material, other equipment etc.) will increase the production thus reducing the time and delay.

A proper general construction plan should define the optimal position of the tower cranes. According to (Tam et al., 2001) and (Zhang et al., 1999) in order to lift load at supply point (S) with the weight w, tower crane should be placed within a circle centered at S and with lifting radius R, where R is the minimum of the tower crane's jib length (Cr) and operating radius (r) obtained from load chart. In the proposed model, it is possible to consider more than one demand point for each supply points. In reality, there may be more than one feasible area within a construction site. A tower crane can handle two tasks, if it is located within the area of intersection between than (fig 1).

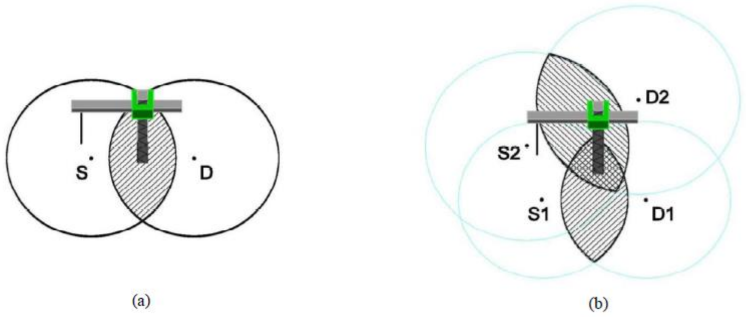

Fig 1: Feasible task area for supply (S) and demand (D) points (a) single task (b) multiple task (adopted from Irizarry and Karan, 1999)

If there is no overlap between tasks, then a single tower is not enough to handle both tasks. The geometric closeness of tasks can be measured by the size of the overlapping area (the larger overlapping area, the greater closeness). A larger overlapping area between two or more cranes may result in longer presence of the cranes in the shared area and therefore there will be a higher risk of collision (Shapira and Simcha, 2009b). Thus, the model searches for places with minimum overlapping area between cranes and their surrounding facilities.

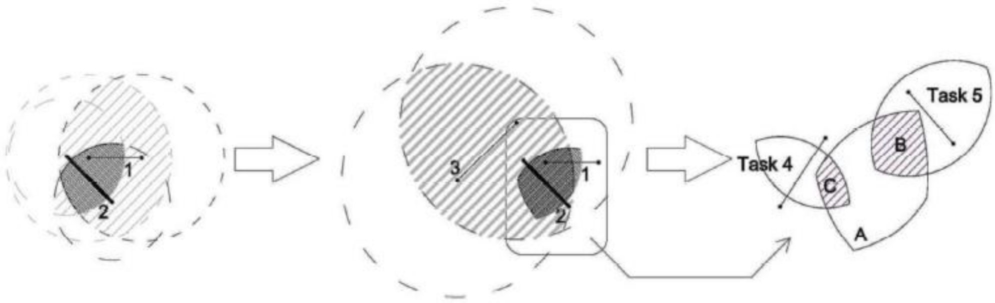

Fig 2: Task closeness (adopted from Zhang et al. 1999)

3. Case Study

In this case study Tower Crane Management on a commercial project in Moscow, Russian Federation is analyzed. The project consists of 420,000 m² GFA (hotel, office buildings and residential with 2 to 3 floors of underground parking). The project was financed by international bank and the Main contract was appointed under cost plus (open book) guaranteed maximum price contract. Time programme was previously agreed, and was exposed to many risks due to challenges in logistics, weather conditions, subcontractor performance and coordination etc.

Employer (Investor) wanted to optimize the crane usage for their maximum benefit and they also wanted it to be dismantled within two months after the completion of concrete works.

Tower cranes are intensively used during structural – concrete works, for vertical transportation of reinforcement, formwork and sometimes for concreting of walls and columns. Construction of underground and above ground is different because of more activities which is performed in parallel with concrete works (waterproofing, excavation, dewatering, protection of foundation pit) below level ±0,00, and programme of works depend on coordination, and technological links between activities. Tower cranes for construction above level ±0,00 are mostly used for concrete works and it is also used for the logistics of other materials for brickwork partitions and façade in parallel depending on the availability. For the optimal use of tower cranes, project phases should be appropriately defined and based on that number of cranes for each phase to be planned.

UNDERGROUND PART

		Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	OVERALL
CONCRETE PLAN acc to SVARGO programme		481	3528	6104	7440	7860	8269	7908	6386	6386	6180	4160	**64702**
(o) Number of cranes/month				1.3	3.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
average number of people work under crane				91	245	350	350	350	350	350	350	350	
(F1) production with tower cranes				1456	3920	8050	8050	8050	8050	8050	8050	8050	
production with mobile cranes		481	3528	1500									
MAX CONCRETE PLAN acc to CRANE PLAN		**481**	**3528**	**2956**	**3920**	**8050**	**8050**	**8050**	**8050**	**8050**	**8050**	**8050**	**67235**

CONCLUSION : production of around 65,000 m3 in 11 months (8-9 months cranes on site) need 5 tower cranes

Assumptions:
Crane installed on site

crane №1	30-Jan-15
crane №2	20-Feb-15
crane №3	1-Mar-15
crane №4	15-Mar-15
crane №5	1-Apr-15
add crane №1	
add crane №2	

(A) Optimal number of workers per crane	**70**
(B) Winter productivity (m3 concrete/month/worker)	**16**
(C) Optimal productivity (m3 concrete/month/worker)	**23**

ABOVE GROUND PART	gross area (m2)	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16
Building 6	22638			3773	3773	3773	3773	3773	3773				
Building 7	22627							3771	3771	3771	3771	3771	3771
Building 9	6875									1719	1719	1719	1719
Building 10	28039					4006	4006	4006	4006	4006	4006	4006	
Building 11	34110	4873	4873	4873	4873	4873	4873	4873					
Slabs / month (m2)		4873	4873	8646	8646	12652	12652	16423	11550	9496	9496	9496	5490
(D) Average production (m2 slab/month)	9524												
(F2) Number of cranes accorting to formula 2	6.3												

CONCLUSON: additional two cranes should be installed

(E) For above ground calculation (m2slab/crane/month) **1500**

FORMULA 1 = (o) * (A)* [(B) or (C)]

FORMULA 2 = (D) / (E)

Table 3 – Number of crane calculation based on concrete plan and proposed production rates

Maximum quantity of concrete planned to be poured monthly on that construction site was 8,000 m³ for the below ground works. Simple calculation based on production rates proposed in the above chart gives us the optimum number of cranes to be used is five with number of people – 350 productive skilled workers to achieve the planned monthly concrete works of 8000 m³. In actual additional 2 cranes were installed to achieve the planned concrete plan.

For the approximate estimation of crane usage duration, planning tools like, Microsoft Project, Primavera, Asta Power Project etc. are used.

According to the contract milestone table and duration, time programme was prepared using software Primavera Enterprise P8.2 with works breakdown structure (WBS) as belowground and above ground. Concrete quantities were loaded as resources, with linear distribution as shown in the fig 3 and histogram of concrete to be poured monthly is obtained. This plan is very similar to one presented in the table 3. Also, the crane allocation is shown in the programme as ‘level of effort’ activities as separate WBS.

In presented case concrete distribution was distributed as linear, but there is possibility to set distribution as front or back loaded, bell shaped, normal distribution, etc. In the table 3 it’s been already presented the concrete plan with crane calculation and number of people required.

Maximum concrete poured per month = number of cranes x number of workers per crane [70] x production/worker/month (calculation on the above part of table 3).

Number of cranes = square meter of slabs poured per month / average production per crane (calculation on the below part of table 3).

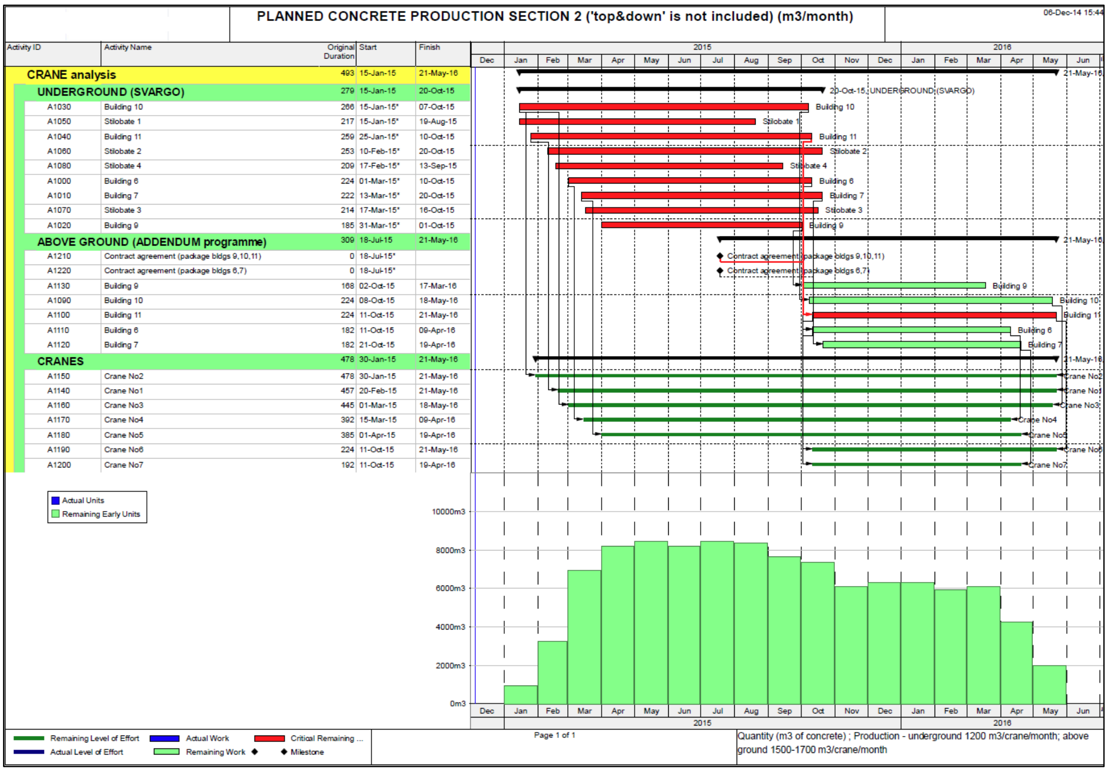

Fig 3 – Planned concrete production and crane loading during concrete works

Generally, in the table 3 and fig 3 shows the same excercise, but for better understanding and presentation it is proposed to calculate concrete plan using planning and scheduling software in fig 3, and then it is exported to Microsoft Excel table, as in the table 3 for the calculation of concerete plan, labor and number of cranes required.

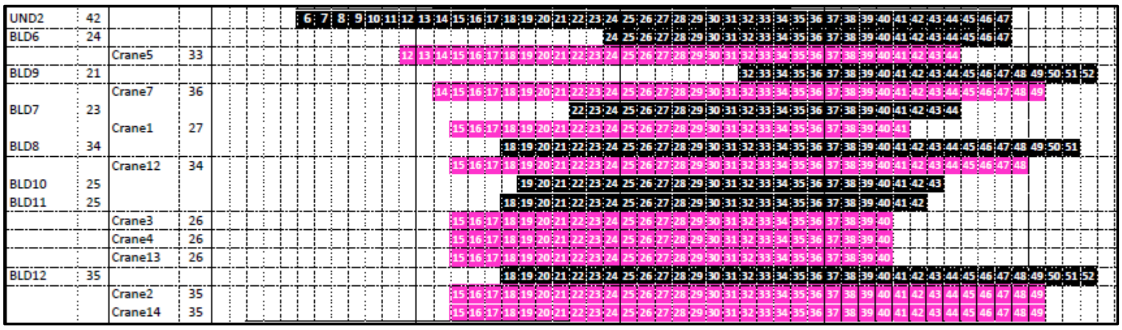

Fig 4 – Time programme and crane engagement per building

On the Fig 4 is shown in black color planned period for construction, and in pink color planned period of crane installation on site, similar presentation as on fig 3.

Renting company proposed number of cranes and layout presented on fig 5. Using methodology of supply and demand points, conflicted areas, and calculation of production rates, it was concluded that number of cranes is very high and there are many conflicted areas between cranes.

A large overlapping area between two or more cranes may result in longer presence of the cranes in the shared area and therefore there will be a high risk of collision between the cranes. Even though with this number of cranes, high productivity is possible, but there will be low percentage in utilization of individual crane. Also, cost of installation and dismantling of cranes in this case is very high. Therefore the crane company's proposal was rejected.

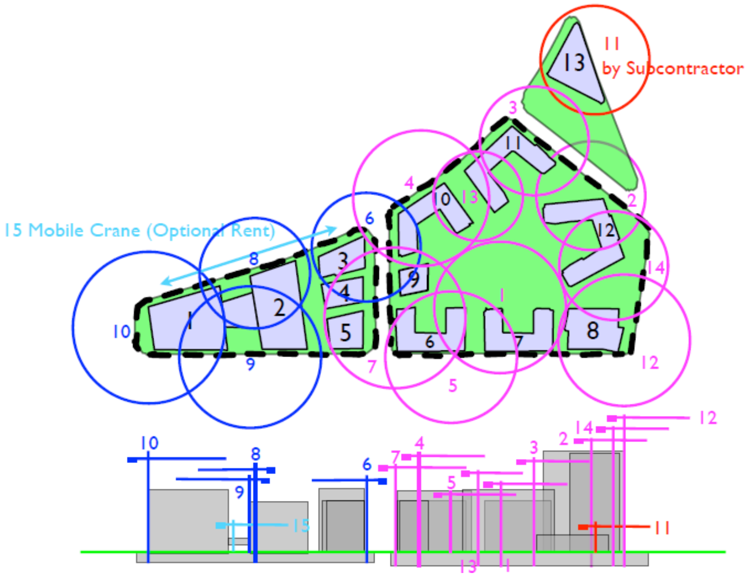

Fig 5 – Proposed crane layout by renting company

For phase 2, which is point of concern in this paper, crane company has proposed nine cranes but according to calculation in table 3 with assumptions sufficient number of cranes to achieve programme is 6,3 (7). General contractor analyzed crane company's layout, position of buildings (demand points), supply points, and proposed the tower crane strategy to achieve the project programme.

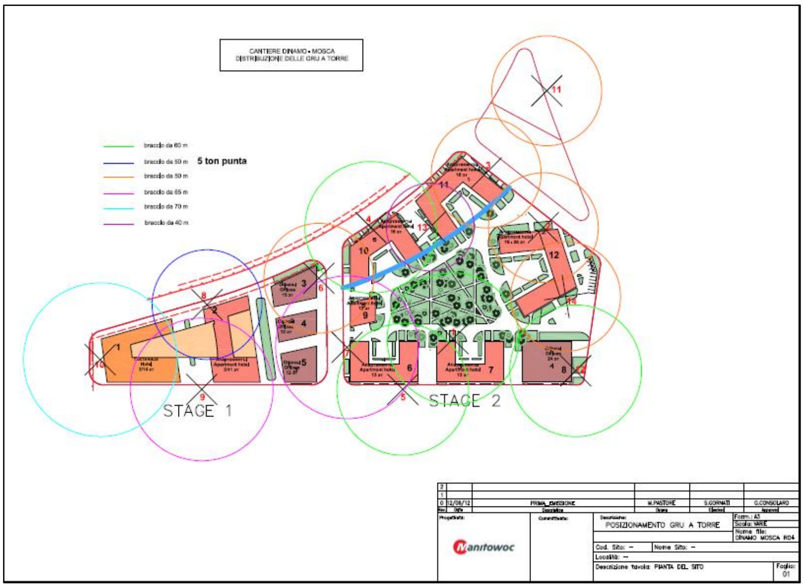

Fig 6 – Proposed tower cranes for commercial project by crane renting company

Calculation in table 4 is overall crane usage on construction site, based on concrete works programme. From that calculation, it is possible to define cost of cranes and to analyse possible solutions for crane usage. That calculation is based on very aggressive approach of cranes being dismantled 2 months after the completion of concrete works.

	CRANES					waiting time (6)-(1)	PROGRAMME SENT TO THE EMPLOYER		
	crane number	start	finish	finish + 60 days	renting period (months)		start	finish	duration (months)
		(1)	(2)	(3)	(4)		(6)	(7)	(8)
Building 6	4	25-Nov-15	2-Jul-16	31-Aug-16	9	39	3-Jan-16	2-Jul-16	6.0
Building 7	5	25-Nov-15	30-Oct-16	29-Dec-16	13	159	2-May-16	30-Oct-16	6.0
	7	3-Jan-16	30-Oct-16	29-Dec-16	12				
Building 9	3						3-Jul-16	17-Dec-16	5.6
Building 10	3	25-Nov-15	17-Dec-16	15-Feb-17	15	97	1-Mar-16	10-Oct-16	7.4
	2	25-Nov-15	10-Oct-16	9-Dec-16	13	97			
Building 11	1	21-Nov-15	1-Jul-16	30-Aug-16	9		21-Nov-15	1-Jul-16	7.4
	6	15-Dec-15	1-Jul-16	30-Aug-16	9				
					80				
Construction period (sum (8))					32				
Addition 2 months* 7 cranes					14				
Zone of 'top&down'									
Building 8	A	1-Aug-15	3-Sep-16	2-Nov-16	15		4-Oct-15	3-Sep-16	11.2
Building 12	B	15-Jul-15	4-Sep-16	3-Nov-16	16		7-Sep-15	4-Sep-16	12.1
	C	15-Aug-15	4-Sep-16	3-Nov-16	15				
					46				

Table 4 – Overall crane engagement per building

After analyzing the proposal from crane renting company (shown on fig 6) and calculation presented in table 3 and construction time schedule, decision has been made to organize vertical transportation with tower cranes, as in fig 7. Although calculation shows it requires only 7 cranes but after expert analysis with all possible assumptions, decision is been made to install 8 cranes for the construction of phase 2. The main reason for installation one additional crane is due to restricted position of supply points, and to be on the safe side in case of any unknown risk and to reduce time for construction. With this strategy utilization of tower cranes has been made higher than average referenced in the literature.

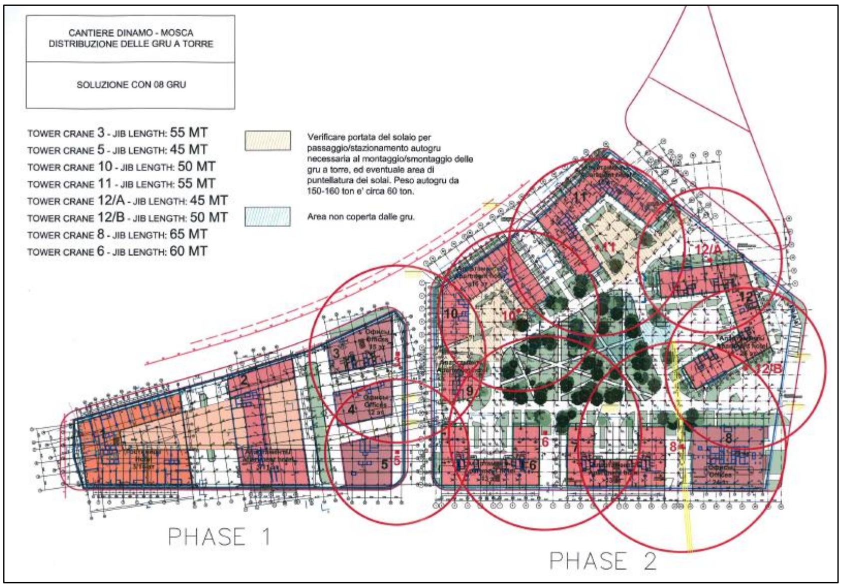

Fig 7 – Construction plan with position of tower cranes for phase 2

4. Conclusion

This overview and analysis is attempt to present and clarify main topics related to crane analysis, calculation and management in high rise construction. Case study based on previous project experience should be analysed and confirmed at the end of the project with statistical data collected during execution period. Proposed approach of number of cranes calculation can be improved with different productivity rates, which depend on specifics of construction site, building type, climate conditions, technological and organizational factors, etc. Right possition of crane should be defined considering supply and demand points, and that is mostly geometrical approach. This problem always should be analysed from planning perspective as productivity and duration of crane usage on construction site make great impact over many aspects of the construction process.

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A Mixed Integer Model for Optimization of Discrete Time Cost Tradeoff Problem

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Abstract

In construction projects, activity durations can be expedited by allocating additional resources. Decreasing activity durations by means of crashing, usually leads to increase in the direct expenses. This trade-off between time and cost is called as the time-cost trade-off problem. Since in practice many resources are available in discrete units, numerous research has focussed on the discrete version of this problem called the discrete time-cost trade-off problem (DTCTP). Achieving the project schedule that satisfies the project requirements at an optimum cost is crucial for effective scheduling and management of construction projects. Despite the importance of DTCTP, very few research focused on generating and solving of large scale instances. The objective of this proceeding is to generate large scale instances that reflect the size of real-life construction projects and to solve these instances using mixed integer programming method (MIP) to enable a benchmark set with optimal solutions. Within this context, large scale instances that reflect the size of real-life-size construction projects are generated. A MIP model is developed and the majority of the instances is solved to optimal using GUROBI optimizer.

Keywords: cost optimization, discrete time-cost trade-off problem, exact methods, mixed integer programming, project management

1. Introduction

Construction projects have a certain scope, budget and schedule. Especially, throughout a construction project, budget and schedule have essential effects on each other. Schedule of a project may be shortened by means of expediting activities that requires working overtime or increasing crew size. Accordingly, crashing a project schedule leads to additional cost. This trade-off between activity durations and costs is defined as time cost trade-off problem (TCTP). In the construction industry, the majority of resources are available in discrete units; hence, numerous researches have been conducted on the discrete version of the problem called as discrete time cost trade-off problem (DTCTP).

In the literature, DTCTP has been examined in terms of three categories as deadline problem, budget problem and time-cost curve (Pareto front curve) problem. Deadline problem aims to minimize the total cost with respect to a given project deadline. Budget problem, on the other hand, aims to minimize the project duration within a given budget. The Pareto front problem aims to construct complete and efficient time-cost profile over the set of feasible durations [1].

Methods proposed to solve DTCTP can be classified as exact methods, heuristics and meta-heuristics. De et al. (1997) [2] define DTCTP as strongly non-polynomial hard (NP-hard). Hence, exact methods may require significant amount of computational time [3]. On the other hand, exact methods guarantee optimality. Hence, they provide a benchmark to evaluate the results of heuristic and meta-heuristics. As a pioneer study within the context

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of heuristics, Siemens (1971) [4] presented the Siemens approximation method (SAM) for the cost optimization problem with strict deadlines, and implemented it on a problem with eight activities. Goyal (1975) [5] proposed a modified version of SAM and used the same example with 8 activities. Moselhi (1993) [6] developed a heuristic based on schedule compression. Apart from these, numerous meta-heuristics have been presented for the DTCTP. Hegazy (1999) [7] developed a genetic algorithm (GA) for the cost optimization problem. Sonmez and Bettemir (2012) [8] developed a hybrid strategy based on GAs, simulated annealing (SA), and quantum simulated annealing techniques (QSA) for the cost optimization problem. Zheng (2015) [9] presented a GA for the discrete time-cost-environment trade-off problem. Zhang et al. (2015) [10] proposed a GA for the DTCTP in repetitive projects. Elbeltagi et al. (2007) [11] presented a shuffled frog-leaping algorithm for the cost optimization problem. Vanhoucke and Debels. (2007) [1] developed a meta-heuristic involving tabu-search and truncated dynamic programming for the cost optimization problem with strict deadlines. Abdel-Raheem and Khalafallah (2011) [12], proposed an evolutionary algorithm which simulates the behavior of electrons moving through electric circuit branches for the cost optimization problem. Tavana et al. (2014) [13] presented two multi-objective procedures based on Ɛ-constraint method and dynamic self-adaptive evolutionary algorithm for the discrete time-cost-quality trade-off problem. Elbeltagi et al. (2005) [14] and Bettemir (2009) [15] adopted the particle swarm optimization method (PSO) for the cost optimization problem.

In terms of exact methods, mixed integer programming (MIP), dynamic programming (DP) and branch and bound algorithm are the most widely known examples in the literature. Meyer and Shaffer (1963) [16], Crowston and Thompson (1967) [17], Crowston (1970) [18], Harvey and Patterson (1979) [19] are the pioneer studies solving TCT with mixed MIP algorithms., Liu et al. (1995) [20] solved TCT problem for a network with seven activities in Microsoft Excel environment linear and integer programming., Moussourakis and Haksever (2004) [3] presented a flexible MIP model for TCT problems. The term flexible represents that the model has the capability to solve different TCT problems by applying minor modifications. Deadline problem was studied with a problem including 7 activities. Vanhoucke (2005) [21] proposed a branch and bound algorithm for the cost optimization problem with strict deadlines and time-switch constraints. The algorithm is capable of solving instances with up to 30 activities. Akkan et al. (2005) [22] provided lower and upper bounds for the cost optimization problem with strict deadlines. Hazir et al. (2010) [23] presented an exact method based on Benders Decomposition for the duration optimization problem, and was able to solve instances including up to 136 activities with 10 modes within 90 minutes. Szmerekovsky and Venkateshan (2012) [24] studied four integer programming formulations for irregular time-cost trade-offs and achieved optimal solutions for instances including up to 90 activities.

In spite of existing studies, there is a gap in the literature in terms of exact methods that are applicable to medium to large scale DTCTPs reflecting the size of real-life construction projects. Liberatore et al. (2001) [25] indicates that a real-life construction project consists more than 300 activities. Hence, the main objective of this paper is to generate medium and large size problem instances including delay penalty and to provide a MIP model for solving these instances.

2. Problem Set Generation

There are few popular benchmark instances for DTCTP in the literature. The network generated by Feng et al (1997) [26] is one of them. However, problem includes only 18 activities. Within the scope of this study, medium and large scale problem instances are generated using ProGen/max random network generator developed by Schwindt (1995) [27].

Project networks are developed with four different complexity indexes. In ProGen/max, complexity index is represented by Thesen restrictiveness coefficient. Accordingly, four different Thesen restrictiveness coefficients of; 0.2, 0.4, 0.6, and 0.8 are used for networks. For each of these coefficients, networks including 50, 100, 200, 500 and 1000 activities are generated. Details of the problem sets are provided in Table 1.

Table 18: Parameter Inputs Entered to ProGen/max for Different Number of Activities.

Parameter	50 Activities	100 Activities	200 Activities	500 Activities	1000 Activities
Minimal Number of Initial Activities	1	1	1	1	1
Maximal Number of Initial Activities	12	20	20	20	20
Minimal Number of Terminal Activities	1	1	1	1	1
Maximal Number of Terminal Activities	12	20	20	20	20
Maximal Number of Predecessor Activities	12	20	20	20	20
Maximal Number of Successor Activities	12	20	20	20	20
Degree of Redundancy	0.1	0.1	0.1	0.1	0.1

ProGen/max is actually designed to generate problem networks for resource constraint project scheduling. The network generator does not create time-cost modes for DTCTP. Hence, it is utilized only for formation of networks. Time-cost modes for the created networks are prepared in Microsoft Excel 2010. Determination of the modes is done according to Akkan et al. (2005) [22]. For the time-cost modes, three intervals including 2-5, 6-10, and 11-15 modes are used. Duration of each time-cost mode is selected randomly between 3 days and 123 days. This interval is divided to the number of modes accordingly. For instance, if number of modes for an activity is five:

- duration of the first mode is chosen between 99 days and 123 days,
- duration of the second mode is chosen between 75 days and 98 days,
- duration of the third mode is chosen between 51 days and 74 days,
- duration of the fourth mode is chosen between 27 days and 50 days,
- duration of the fifth mode is chosen between 3 days and 26 days.

The amount of direct cost for the first mode is determined randomly between 100 USD and 50000 USD. Costs for the remaining modes are determined according to following formula used by Akkan et al. (2005) [22].

$$c_{k+1} = c_k + s_k * (d_k - d_{k+1}) \tag{2.1}$$

where,
c_{k+1} : cost value for time-cost mode $k+1$
c_k : cost value for time-cost mode k
s_k : randomly generated time-cost slope value
d_k : duration value for time-cost mode k
d_{k+1} : duration value for time-cost mode k

Randomly generated time-cost slope values are determined between 10 and 100. In all the created networks, there are two dummy activities representing the start and finish of the project, which do not have a duration and cost. Time-cost modes of a sample network is given in Table 2.

Table 19: Time-Cost Modes for Activities.

Activity ID	# of Modes	Dur#1	Cost#1	Dur#2	Cost#2	Dur#3	Cost#3	Dur#4	Cost#4	Dur#5	Cost#5
1	4	95	40683	74	41959	44	43617	20	44503		
2	4	108	14530	71	14901	38	17063	14	19013		
3	3	120	5601	75	6847	12	7696				
4	3	117	47388	69	49194	35	51688				
5	5	115	12836	97	13791	52	18146	43	18371	6	21693
6	3	92	29250	74	30592	22	32809				
7	5	100	48919	80	49690	60	49926	38	50190	17	52280
8	4	95	14053	63	16392	59	16499	15	19174		
9	4	96	3924	70	5456	56	5610	27	6352		
10	4	120	28039	86	30314	58	32393	13	33346		
11	5	110	38588	77	40499	69	41254	35	42681	17	44280
12	5	115	34151	95	34925	61	36344	40	37703	18	39410
13	3	95	3014	44	4742	6	8034				
14	3	119	31825	50	38677	26	41035				
15	5	118	13988	97	16003	57	16404	28	18819	17	19032
16	5	114	13620	83	16051	67	16458	42	18418	10	19754
17	5	106	7972	80	8538	56	9683	37	10291	17	10960
18	4	114	44660	92	45669	42	49528	24	50825		
19	3	107	48807	64	50401	38	50807				
20	4	121	27062	72	28688	42	29492	5	31251		
21	4	98	40094	77	40641	47	43503	31	44124		
22	4	104	7081	84	7618	45	10789	30	10949		

Generally, construction projects include a delay penalty. Therefore, a delay penalty is included in the problems. The project deadline and delay penalty are determined by:

$$Deadline = \frac{CPMMax - CPMMin}{2} + CPMMin \tag{2.2}$$

$$\text{Cost of } Delay\ Penalty = Indirect\ Cost * 2 \tag{2.3}$$

where

$CPMMax$: Maximum CPM duration calculated by taking the longest duration in time-cost modes of the activities

$CPMMin$: Minimum CPM duration calculated by taking the shortest duration in time-cost modes of the activities

$Deadline$: Project deadline

Using this model, delay penalty is added to project networks. Cost of delay penalty is determined as the double of indirect costs for each network. If the project duration exceeds the defined deadline, delay penalty is added to the total cost.

There are four different complexity indexes and 3 different mode intervals for project networks having 50, 100, 200, 500, and 1000 activities. 10 instances are prepared for each set. Details of the sets are shown in Table 3. A total of 600 test instances are prepared. The daily indirect cost is set as 250 USD for networks having 50 activities. For the rest of the networks, daily indirect cost is set as 500 USD.

Table 3: Number of Problem Sets Prepared for DTCTP Analyses

	Number of Time-Cost Modes												
	2--5				6--10				11--15				
	Thesen Restrictiveness Coefficient				Thesen Restrictiveness Coefficient				Thesen Restrictiveness Coefficient				
	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	
Number of Activities	Number of Test Instances				Number of Test Instances				Number of Test Instances				Daily Indirect Cost (USD)
50	10	10	10	10	10	10	10	10	10	10	10	10	250
100	10	10	10	10	10	10	10	10	10	10	10	10	500
200	10	10	10	10	10	10	10	10	10	10	10	10	500
500	10	10	10	10	10	10	10	10	10	10	10	10	500
1000	10	10	10	10	10	10	10	10	10	10	10	10	500

3. Model Description

In order to minimize the total cost of the projects comprised of direct and indirect costs, the following model based on De et al. (1995) [28] is proposed.

3.1. *Sets*

Pd_j : Predecessors of activity j
S : Activities in the network (exluding dummy activities)

3.2. *Parameters*

dc_{jk} : cost of activity j for time-cost mode k
i_c : daily indirect cost
d_{jk} : duration of activity j for time-cost mode k
$m(j)$: number of time-cost modes for activity j
d_p : daily delay penalty cost

3.3. *Variables*

Ft_j : finish date of activity j
Ft_h : finish date of activity h
x_{jk} : binary variable which is 1 if time-cost mode k is chosen to realize activity j, if not 0.
D : total duration of the project
D_{delay} : amount of delay
$D_{deadline}$: project deadline

3.4. *Mixed Integer Programming Model*

$$\min \sum_{j=1}^{S} \sum_{k=1}^{m(j)} dc_{jk} x_{jk} + D i_c + d_p D_{delay} \tag{3.1}$$

Constraints:

$$\sum_{k=1}^{m(j)} x_{jk} = 1, \quad \forall j \in S \tag{3.2}$$

$$Ft_j \geq Ft_h + \sum_{j=1}^{S} \sum_{k=1}^{m(j)} d_{jk} x_{jk}, \quad \forall h \in Pd_j \text{ and } \forall j \in S \tag{3.3}$$

$$D \geq Ft_{S+1} \tag{3.4}$$

$$Ft_0 = 0 \tag{3.5}$$

$$D - D_{delay} \leq D_{deadline} \tag{3.6}$$

$$D \geq 0 \tag{3.7}$$

$$D_{delay} \geq 0 \tag{3.8}$$

$$x_{jk} \in \{0,1\}, \quad \forall j \in S, \text{ and } \forall h \in m(j) \tag{3.9}$$

$$Ft_j \geq 0, \quad \forall j \in S \tag{3.10}$$

Objective function (3.1) aims to minimize the total cost of the project that equals to the summation of direct and indirect costs. Constraint (3.2) ensures that only one time-cost mode is chosen for each activity. For instance, if the second mode of Activity 3 is chosen in a sample network, x_{32} value is equal to 1 and x_{31}, x_{33}, x_{34}, x_{35} are equal to 0. Since these values are the multipliers of activity costs, only the selected time-cost mode affects the total project duration. Constraint (3.3) defines that an activity cannot finish earlier than the date represents the summation of activity's duration of the selected mode and the finish date of its predecessors. Constraint (3.4) explains that the project cannot be completed until the final dummy activity is finished. In constraint (3.5), finish date of initial dummy activity is set to 0. Constraint (3.6) represents the relation between the deadline and the amount of delay. The next two constraints (3.7), (3.8) explain that both the total project duration and the amount of delay should be positive values respectively. (3.9) indicates that xjk is a binary variable. The last constraint (3.10) shows that finish dates of all activities must be greater than 0. Finally, the dummy activities (Activity 0 and Activity S+1) do not have any duration and cost.

4. Computational Experiments

GUROBI Optimizer 5.6.3 is used to solve the MIP model given in the previous section. First, problem networks given in Section 2 are modelled in terms of LP format. Then, they are analyzed in GUROBI, with a time limit of 600 seconds for each problem. All experiments are conducted with a desktop computer using Windows 7 Professional Edition (64-bit) operating system with an Intel Core i5 3.10 CPU GHz and a 4.00 GB random access memory (RAM). The number of problem instances that are solved to optimal are in the given in the following Table 4.

Table 4. Number of Problems Solved to Optimal.

	Number of Time-Cost Modes													
	2--5				6--10				11--15					
	Thesen Restrictiveness Coefficient				Thesen Restrictiveness Coefficient				Thesen Restrictiveness Coefficient					
	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8		
Number of Activities	Number of Test Instances				Number of Test Instances				Number of Test Instances				Solved Number of Total Instances	Solution Percentage (%)
50	10	10	10	10	10	10	10	10	10	10	10	10	120	100
100	10	10	10	10	9	10	5	10	10	10	10	10	114	95
200	10	10	10	10	9	9	5	9	6	7	5	8	98	81,7
500	10	10	8	10	5	5	3	2	5	4	6	5	73	60,8
1000	7	6	8	7	3	2	5	4	4	6	1	4	57	47,5

All of the problems consisting of 50 activities are solved within the time limit. As the number of activities in a network increases, the number of solved problems decreases. The CPU time of the problems solved to optimal are shown in Table 5.

Table 5: Average CPU Time in Optimal Cost Solutions

	Number of Time-Cost Modes											
	2--5				6--10				11--15			
	Thesen Restrictiveness Coefficient				Thesen Restrictiveness Coefficient				Thesen Restrictiveness Coefficient			
	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
Number of Activities	CPU Time (seconds)											
50	0.12	0.14	0.24	0.13	0.41	0.87	1.04	0.58	0.82	1.06	3.33	0.93
100	0.54	0.28	1.28	0.33	176.34	56.54	2.08	0.96	0.03	0.35	1.33	1.22
200	8.34	0.54	2.76	3.32	161.23	13.54	77.80	7.78	168.44	86.68	11.40	3.00
500	29.20	9.69	22.32	24.29	134.22	96.39	16.26	175.76	81.26	145.20	220.17	38.13
1000	20.75	54.02	68.28	90.38	303.93	267.66	201.60	119.37	316.39	87.62	58.37	285.16

Results given in Table 5 are compared to similar studies in the literature. Hazir et all (2011) [23] solve a 136-activity network with an MIP algorithm in 19139.61 seconds. Furthermore, the model proposed by Szmerekovsky and Venkateshan (2012) [24] require a CPU time of 206 seconds to solve a 90-activity network.

5. Conclusion

In this study a total of 600 problems DTCTP instances, including 1000 activities is generated. A MIP model including a delay penalty is used to solve the benchmark problems to optimal. The majority of the small and medium scale instances and some of the large scale instances of are solved to optimal, within 600 seconds with GUROBI Optimizer 5.6.3. Hence, optimal solutions can be achieved for the deadline problem for evaluating the results of the heuristic and meta-heuristic methods. The CPU time of the MIP model presented can be decreased by using parallel processing methods which is a potential area for a future study.

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Floyd-Warshall in Scheduling Open Networks

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Abstract

CPM, PERT, MPM, PDM are well known abbreviations and techniques extensively used at estimating and managing time performance of different kind of - amongst them of construction - projects. Common in them is that they are based on and demonstrated by the analogy of a special problem in Graph Theory namely the problem of finding The Longest Path(s) between two nodes in a weighted directed graph. It is less frequently mentioned that the problem has its pair as a 'dual' problem that is known as The Minimal Potentials' Problem interpreted on a set of potentials having pair-wise relative restrictions (lower and/or upper bounds) amongst the potentials. Main differences of the techniques mentioned at the beginning are in preparing and interpreting input and output data and in correspondence of graph elements and of time characteristics (events, processes, lead and lag times) of project components. It is also common in them that determining feasible solution(s) is usually based on a kind of roll-on typed algorithm (e.g. Dijkstra's Algorithm) calculating early and late times via series of consecutive steps starting from a base point (from start or from finish) increasing the set of examined elements of the graph step by step in an appropriate order (forward pass and backward pass), thus solving actually the 'dual' problem. Applying a modified Floyd-Warshall algorithm all-pair longest paths can be determined and identified, and all difficulties of and restrictions on composing the logical time model of the project (represented by the graph) can be eliminated except of the only thing: exclusion of positive loops in the weighted directed graph.
The paper discusses application of modified Floyd-Warshall algorithm to calculate the time model of the project with no concern on whether it has one or more starting and/or ending point(s), whether it includes logical loop(s) or not, whether it is a connected model or not, whether it necessitates positive (lower bound) or negative (upper bound) or multiple restrictions amongst the time data of the project elements or not – that is: to schedule open networks.

Keywords: Construction Management, Network Techniques, Open Networks, Floyd-Warshall, Scheduling.

1. Introduction

In early applications (CPM [3], PERT [4]) graph structures for scheduling had been restricted to a tightly defined topology referred as Network. By its definition a network is a directed weighted connected graph with one starting node, with one ending node, with no arrow loops and with no negative weights on the arrows. Necessity of these restrictions on graph structure can be ascribed mainly to early solution algorithms and to capabilities of early computers the applications had been run on. (In our context, later on, we use the terms “arrow”, “edge” and “directed edge” as synonyms. Similarly, when mentioning a “graph” or “network” we mean a directed weighted graph structure.)

It can be shown that without the rest of before mentioned restrictions, on general directed weighted graphs, valid and calculable time models can be constructed for use of any level of project and/or production management. Moreover, in widely known MPM [5,6] and PDM [4] techniques loops and negative weights have been implicitly integrated in the models resulting in no any unexpected, contrary and/or unsolvable conditions. Furthermore the practice of originating all initial steps/tasks from one single starting node in the model, and/or directing all finishing procedures/tasks into one single ending node may integrate unintended and misguiding information when modelling progresses in multi-project management context.

The need for revising restrictions of „traditional“ network techniques emerged at a joint R&D project of Hungarian Railways Company (MÁV) and of Budapest University of Technology and Management (BME), 1989-93, aiming to develop a Computer Aided Decision Support System for planning and managing reconstruction and maintenance works on the Hungarian railways’ system.

The challenge the management had to face was the task of Permanent Scheduling of works on a three-years slipping time-span looking over thousands of jobs with accuracy of minutes. No expressed start, no expressed end, widely diverging responsibilities, dispersed locations all around the country, but one complex must-be-operating, under-traffic railway system and a restricted common pool of some significant specialized resource series.

Traditional Scheduling techniques (including traditional Network Techniques) proved to be insufficient. „The project to be scheduled was not a project."

2. The scheduling problem

The scheduling problem, with tasks of pre-set durations and with pre-set precedence relations amongst them can be derived from the primal-dual problem-couple of The Longest Path Problem on a weighted graph (CPM, PERT) and The Minimum Potentials' Problem with lower and/or upper bounds on differences of pairs of potentials (MPM/PDM).

Exposed or not, usual algorithms developed for to solve the scheduling problem are focusing on The Minimum Potential's Problem meanwhile executing a kind of Implicit Labelling Technique such as Dijkstra's greedy algorithm for finding the shortest paths on a graph [1]. (Calculations are started at the origin and are rolling towards the terminal node, then back – "forward pass" and "backward pass").

Setting The Longest Path Problem in the focus of examinations necessity of restrictions on the graph structure can be reduced radically. Length of any path on a weighted graph is defined as a pure sum of weights of the arrows constituting the given path. At a pure addition it is irrelevant in what an order the numbers are added together. Thus, no need for pre-set origin and for pre-set terminal node for calculation. Neither the count of numbers is relevant. Length and elements constituting the longest paths can be identified. And, knowing the longest paths time potentials can be assigned along them to the nodes and arrows as early and late times.

2.1. Scheduling with homogenous restrictions

Preserving the inter-relation between the Longest Path Problem and The Minimum Potentials' Problem the Scheduling Problem can be summarized as:

$$\pi_i \geq 0; \quad \forall i \quad i \in \mathrm{N} \tag{1}$$

$$\pi_j - \pi_i \geq \tau_{ij} \quad \forall ij \quad ij \in \mathrm{E} \tag{2}$$

$$\pi_{\max} \rightarrow \min \tag{3}$$

$$\tau_{ij} \geq 0 \quad \forall ij \quad ij \in \mathrm{E} \qquad \text{(In CPM/PERT models non-negative weights allowed)} \tag{4}$$

(Where N is set of nodes (i), E is set of edges (ij), τ_{ij} is the lower bound also presented by the weight w_{ij} on edge ij, π_i is the time potential to be assigned to the node i)

2.2. Homogenizing mixed restrictions

According to the rules of elementary algebra, multiplying inequality representing bound on difference of a pair of potentials by minus one, any upper bound can be equally substituted by a lower bound (reversing the direction of subtraction, that is direction of edge, and changing the sign of the limit value). Thus, a mixed bounding system can be transformed to a homogeneous one having lower bounds only.

$$\pi_j - \pi_i \leq \tau_{ij} \quad / \cdot (-1) \qquad \text{(upper bound)} \tag{5}$$

$$\pi_i - \pi_j \geq -\tau_{ij} \qquad \text{(upper bound turned to lower bound)} \tag{6}$$

Analogically, any fixed duration of a task can be set by a pair of lower and of upper bounds having the same limit values (τ_{sf}, as duration) between its start (s) and its finish (f).

$$(\pi_f - \pi_s = \tau_{sf}) \quad \equiv \quad (\pi_f - \pi_s \geq \tau_{sf}) \ \cup \ (\pi_s - \pi_f \geq -\tau_{sf}) \tag{7}$$

As a consequence of above, loop of directed edges is given (between the starting and finishing nodes of the task), negative weight is given (upper bounding for fixed duration), while analogy of the Longest Path Problem is still held and the model keeps calculable.

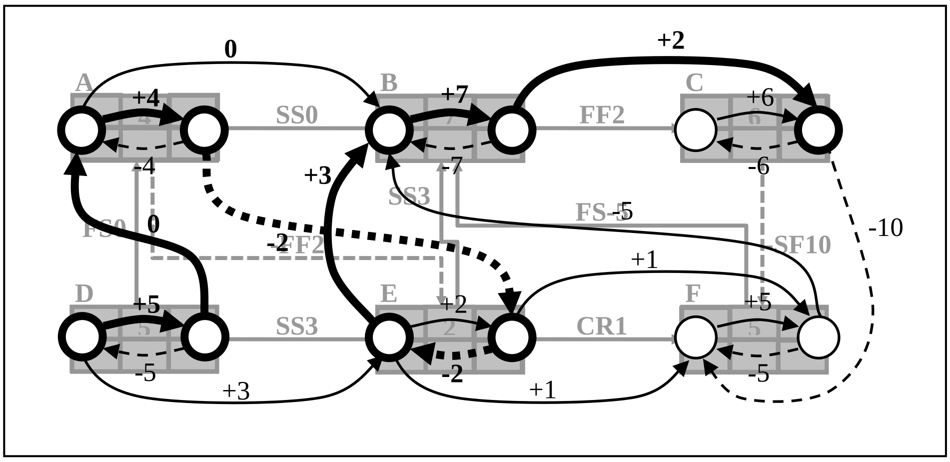

Figure 1. – A radiographic view (standard DiGraph representation) of a typical MPM/PDM network with fixed durations (boxes and arrows in grey in the background), with loops, positive (lower bounds - solid arrows) and negative (upper bounds - broken arrows) weights.

The only problem may emerge when any positive loop (sum of weights of edges of the loop is greater than zero) gets involved in the model. (Here we have to mention that researches are going on studying behavior of positive loops used as generators of periodically repeated jobs in production time models.)

A less-known interesting consequence of negative weights in the model is the phenomenon called Paradox Situation, when decreasing the duration of a task may result in an increment in completion time of the project. Such a situation may occur when edges with negative weights are involved in the longest path. (Consider MPM task E in Figure 1.)

3. The Modified Floyd-Warshall Algorithm

Implying its Computing Science origin the much cited Floyd-Warshall algorithms [2,8] are frequently explained as tripartite loop routines organized around a single core of simple calculations on a proper tabular representation of the graph. (This later is usually referred as weighted structure matrix or distance matrix of the graph).

Though it is rarely declared (or less evident) main idea of Floyd-Warshall routines is based on a simple triviality. Namely: considering a connected directed graph, if a path exists from node *i* to node *k* and also a path exists from node *k* to node *j*, then consequently a path do exists from node *i* to node *j* (at least the one via node *k*). In this context we do refer node *k* as a transfer node on a path from node *i* to node *j*. (Principle of transitivity of nodes)

Extending the above triviality it can be stated that in case of any graph there exist path from all the nodes from which path leads to a selected transfer node *k* to all the nodes to which path leads from the mentioned node *k*. It means that testing all the nodes of the graph as transfer nodes one by one we can gain certainty of existence of any and all the paths throughout the entire graph. It is also easy to see that tracking nodes this way all existing paths consisting of at least two edges on the graph get be considered once and only once. With information about the single edges in the other hand we can conclude that all-pairs analyses of the graph can be kept in hand this way. Some managerial problems solvable this way have been discussed by Vattai, 2006 [7].

3.1 General formulation of all-pairs calculations

For discussing the scheduling problem referred in the heading we use the denotations below:

G[N,E]	: refers to a graph (G) having the set of nodes (N) and the set of edges (E)
G[N,E,W]	: refers to a graph as above but having weights (W) on edges respectively
P	: refers to the set of all paths on the graph
P_{ij}	: refers to all paths from node i to node j on the graph
O^+	: refers to set of positive origins of the graph
T^+	: refers to set of positive terminal nods of the graph
ij	: refers to the edge from node i to node j on the graph
M	: marker value in tabular representation of graph, reads „no connection”
$\underline{\underline{W}}$	: initial tabular representation (weighted structure/adjacency matrix) of the graph
w_{ij}	: element of $\underline{\underline{W}}$ referring to the „weight” of the edge from node i to node j
n	: number of nodes of the graph
k	: index of outer cycle, also refers to transfer node actually selected
$\underline{\underline{A}}^k$	: transformed matrix representation of the graph in cycle k
a_{ij}^k	: element of $\underline{\underline{A}}^k$ referring to ij pair of nodes (connection from i to j)
a_i^k	: row vector i of matrix $\underline{\underline{A}}^k$
$á_i^k$	: column vector i of matrix $\underline{\underline{A}}^k$
i,j	: running indices of nodes, also referring to rows and columns of matrices

Using denotations above general routines of selecting nodes as transfer nodes one by one (outer cycle) and testing connections (inner cycles) together with performing necessary modifications if any (core) can be formulated as shown in Figure 2.

$\underline{\underline{A}}^0 = \underline{\underline{W}}$ { initialization }

$\underline{\underline{A}}^k = \Phi(\underline{\underline{A}}^{k-1}), \quad k = 1,2,\ldots,n$ { outer cycle }

Inner calculations of matrix-transformation function Φ: { inner cycles and core }

$$a_{ij}^k = \left\{ \begin{array}{ll} \varphi(a_{ik}^{k-1}, a_{kj}^{k-1}, a_{ij}^{k-1}) \;|\; i\neq k \quad j\neq k \quad a_{ik}^{k-1}\neq M \quad a_{kj}^{k-1}\neq M \quad a_{ij}^{k-1}\neq M \\ a_{ij}^{k-1} \quad \text{otherwise} \end{array} \right\} \forall\, ij$$

where $\varphi(a_{ik}^{k-1}, a_{kj}^{k-1}, a_{ij}^{k-1})$ refers to a properly selected trhee-variable function (core)

Remark: at Floyd (1962) $M = +\infty$ and $\varphi(a_{ik}^{k-1}, a_{kj}^{k-1}, a_{ij}^{k-1}) = \min\{a_{ij}^{k-1}, a_{ik}^{k-1}+a_{kj}^{k-1}\}$

Figure 2. – Formulation of general routines of all-pairs analyses

3.2. All-pairs Longest Path

Algorithms for to calculate $\underline{\underline{A}}^n$ matrix reading all-pairs longest paths are differing from routines used for calculating all-pairs shortest paths in „sign” only as shown in Figure 3.

$M = -\infty$

$$w_{ij} = \left\{ \begin{array}{ll} w_{ij} \;|\; ij\in E \\ M \quad \text{otherwise} \end{array} \right\} \forall\, ij$$

$$\varphi(a_{ik}^{k-1}, a_{kj}^{k-1}, a_{ij}^{k-1}) = \max\{a_{ij}^{k-1}, a_{ik}^{k-1}+a_{kj}^{k-1}\}$$

Figure 3. – Marker value and core function for all-pairs longest distances

By modified Floyd-Warshall algorithm we actually produce a specific Transitive Closure of the graph with values of length of longest paths in all-pairs relation. Here we have to point at that any positive value in the diagonal of the resulting $\underline{\underline{A}}^n$ matrix invalidate the calculation indicating existence of at least one positive loop on the graph.

4. Deriving solution of Potentials' Problem

4.1. Deriving solution of Minimal Potentials' Problem - for closed networks

Having the valid specific transitive closure of the structure matrix of the graph Overall Execution Time (Π) of the project modelled and deadlines (time-potentials) such as Earliest Times (π_j) and Latest Times (π'_i) of events (represented by nodes of the graph) can be read in matrix $\underline{\underline{A}}^n$ almost directly.

$$\pi_j = \max\{0, \max_i a_{ij}^n\} \quad \forall j \tag{8}$$

$$\Pi = \max_j \pi_j = \max_{ij} a_{ij}^n \tag{9}$$

$$\pi'_i = \min\{\Pi, \min_j(\Pi - a_{ij}^n)\} \quad \forall i \tag{10}$$

4.2. Deriving solution of Potentials' Problem - for open networks

We refer a directed weighted graph as „Open Network" if it has more origins and/or more terminal nodes. To identify the chain of arrows of the longest distances on an open network we have to introduce the terms "Positive Origins", and "Positive Terminal Nodes".

A Positive Origin of a graph is a node with at least one leaving arrow of positive weight but with no entering arrow of positive weight. A Positive Terminal Node of a graph is a node with at least one entering arrow of positive weight but with no leaving arrow of positive weight.

It is easy to get convinced that the weight of the first and that of the last arrow of the Longest Path(s) on a Graph having at least one arrow with positive weight cannot be negative. (Leaving the arrows with negative weights from the beginning and/or from the end of a path would result in a „longer" path. Length of a path is pure sum of weights of its arrows.) So any Longest Path must lead from Positive Origin to Positive Terminal Point.

In case of a closed network in a feasible solution of the Minimum Potentials' Problem the minimum time-span between the only (positive) origin and the only (positive) terminal node is provided and it equals to the length of the longest path(s) between them.

To keep this analogy for open networks, that is to keep the correspondence between potentials and path lengths we have to modify the original Potentials' Problem:

$$\pi_i \geq 0; \quad \forall i \quad i \in \mathrm{N} \tag{11}$$

(Non-negative potentials to be assigned to all nodes of the graph.)

$$\pi_{\min} = 0; \tag{12}$$

(Fix the minimum value of the potentials' system to zero.)

$$\pi_j - \pi_i \geq \tau_{ij} \quad \forall ij \quad ij \in \mathrm{E} \tag{13}$$

(Difference of pairs of potentials are limited by lower bounds represented by the weights of edges ($\tau_{ij} = w_{ij}$) of the graph. No restriction on the value and/or sign of the weights.)

$$\pi_j - \pi_i \rightarrow \min \quad \forall ij \quad i \in \mathrm{O}^+ \quad j \in \mathrm{T}^+ \quad \mathrm{P}_{ij} \in \mathrm{P} \tag{14}$$

(The time-span between positive origins and positive terminal nodes between which at least one path exists should be at minimum.)

This way we eliminate false floats from the schedule that would be posed by the original (Minimum) Potentials' Problem. This elimination may get high importance in a multi-project management context such the one referred at the beginning (MÁV) where the Start and the Finish of individual projects inter-related are not mutual and should be handled individually. (Out of some common resources and/or some common interests the local projects have their own preferences.)

$$\pi_j = \max\{0, \max_i a_{ij}^n\} \quad \forall j \tag{15}$$

$$\pi'_i = \min\{\pi_j, \min_j(\pi_j - a_{ij}^n)\} \quad \forall i \quad j \in \mathrm{T}^+ \quad a_{ij}^n \neq M \tag{16}$$

$$\pi_j = \max\{\pi'_i, \max_i (\pi'_i + a_{ij}^n)\} \qquad \forall\, j \qquad i \in O^+ \tag{17}$$

4.3. Identifying the Critical Path (Dominant Sub-Graph)

„Critical Nodes“ of the overall longest path (better said: of Dominant Sub-Graph – frequently referred as „Critical Path”) can be recognized by checking condition if the earliest and latest times equal to each other ($\pi_i=\pi'_i$), while „Critical Edges“ (all between critical nodes) can be recognized by checking if difference of time potentials at ending (π_j) and at originating (π_i) nodes of the edge equals to the weight (w_{ij}) of it.

$$\pi_i = \pi'_i \qquad \pi_j = \pi'_j \qquad \pi_j - \pi_i = w_{ij} \qquad ij \in E \tag{18}$$

All and any Longest Path(s) between any pair of nodes between which any path exist can also be identified with the help of the original structure matrix ($\underline{\underline{A}}^0$) of the graph and the transitive closure of it ($\underline{\underline{A}}^n$) produced by the modified Floy-Warshall Algorithm.

An edge (*ik* or *ij*) is the first or the only edge of a path of the given length (a_{ij}^n) between two nodes (*i* and *j*) if the length (weight) of the edge ($a_{ik}^0\ k\neq j$) and the length of the rest of the path (without that edge) (a_{kj}^n) adds the length of the path (a_{ij}^n) considered or the length of the edge (a_{ij}^0) equals to the length of the path (a_{ij}^n) itself.

$$a_{ij}^n = a_{ik}^0 + a_{kj}^n \qquad \text{or} \qquad a_{ij}^n = a_{ij}^0 \tag{19}$$

Starting from the first node (*i*) of the path to direction of the last one (*j*) of it the edges of the path with the given length (a_{ij}^n) can be identified one-by-one on a forward-pass. This way length of paths and of edges are used as some kind of implicit labels.

Acknowledgement

The author would thankfully evoke the memory of his former tutors, later colleagues and friends three of whom we can never turn for help to any more. Members of the 1989-93 MÁV-BME R&D research team were: Tibor Vígh+, head of Office of Exposed Projects, Hungarian Railways Company; Károly Bacher+, József Monori+, László Neszmélyi and Zoltán András Vattai, tutors of Department of Construction Technology and Management, Budapest University of Technology and Economics.

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Exploratory Factor Analysis of Employee's Actions towards Health and Safety Compliance in Construction

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Abstract

Unreasonable rates of accidents both permanent and non-permanent disabilities and even fatalities are found to be common among the construction industry. The purpose of the study was to determine employee's actions towards Health and Safety (H&S) compliance in construction. Delphi survey method of data collection was used to generate information from academicians and construction professionals (experts). Questionnaires were completed by respondents based on provided indicator or measurement variables to predict employee's actions towards H&S compliance in construction. The ratings of the questionnaire were based on either the impact was considered to be very high, high or medium. The analysis of the data was done using Microsoft EXCEL and the results were presented in charts. Findings from the study showed three measurement variables to have reached consensus using Inter-Quartile Deviation (IQD) with strong consensus and very high impact. Further Exploratory Factor Analysis (EFA) showed five indicator variables to be the determinant of H&S compliance. It can be concluded from the findings that employee's actions are very significant in deriving health and safety compliance in the construction industry.

Keywords: Exploratory factor analysis, employee's actions, compliance, health and safety.

1. Introduction

Occupational Safety and Health (OSH) is concerned with preserving and protecting human and facility resources in the workplace (Friend and Khon, 2007). Hence, standards and guidelines were developed to help the employers and employees to develop their OSH management system. But employees do often go contrary to the aforementioned and leading to occupational safety and health hazards daily worldwide. However, laws and regulations may refer to certain standards and make compliance with them compulsory (British Standard, 2009).

Unsafe actions of employees leading to accident within the work environment is likely to occur when management fail to institute OHS regulations and enforce it. Hence, Creation of positive safety culture within any work environment requires the participation of all workforce, as well as effective communication and trust among all role players (Boshoff (2015). Technical failure and inadequate training coupled with harsh work environment and unsafe methods of working inter alia are among the causes of non-compliance with OSH regulations Othman (2012). Idubor and Osiamoje (2013) posited that safe work environment can determine how issues of compliance with OSH regulations are taken care of by construction firms. Moreover, adequate Occupational Health and Safety (OSH) training and education enhance the OSH performance e.g., compliance with OSH regulation. This paper attempts to substantiate how employee's actions will contribute to H&S compliance in the construction industry. The paper discussed employees' attitude towards H&S compliance in the construction industry.

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2. Research Design/Methodology

Nine experts participated in the study and this number was considered adequate based on literature recommendations from scholars who have previously used the technique. Hallowell and Gambatese (2010) suggested a minimum of eight panelist since most studies incorporate between eight and sixteen panelists. The size of a panel is also related to the characteristics of the study, number of experts' available, geographical representation and capacity of the facilitator. The experts were made up of academics and construction professionals. The rating of the questionnaires was based on the impact of other factors in predicting safe act of workers towards H&S compliance. Microsoft EXCEL, spread-sheet software was used in the analysis of the data obtained. Descriptive statistics such as means, median, standard deviations and derivatives of these statistics were the output from the analysis. The results were presented in a form of a table and a bar-chart.

Further, Social Sciences (SPSS) version 20 software Package was used to evaluate the reliability, discriminant validity and convergent validity of the instrument. The Exploratory Factor Analysis (EFA) based on the 269 cases and discussion in this paper is based on Factor one (F 1) which had five (5) indicator variables as shown in Figure 1. The factor extraction method used to determine the unidimensionality of the elements during the Exploratory Factor (EFA) was Principal Axis Factoring with Oblimin Rotation (PAF Oblimin). The Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was based on the method used by Farrington (2009) to assess the factor-analysability of data.

3. Safe Acts of Workers and Attitudes

Good safety behaviour of employees at their workplace and approach to work can lead to the reduction accidents in the construction industry (Makin & Sutherland, 1994; Christian et al., 2009). The safety needs of employees lie with the employers because it is the requirements of OSH implementation. Hence the formation of good safety behaviour in the construction industry as pointed out by Christian et al., (2009) through effective implementation of occupational safety and health. Both the employer and the employee have similar perception of the respective responsibility of each party for health and safety (H&S) at workplace. The employer is knowledgeable on the set of rules and regulations governing H&S at workplace and the general wellbeing of his employees (Elgood, Gilby and Pearson, 2004). Employees' behavior has been one of the greatest determinants at workplace leading to their safety because their behavior plays a significant role at workplace and contribute to prevention of injury (Schulz, 2004). This argument has been supported by Mustapha, Aigbavboa and Thwala (2016) and indicated that employee's safe act contribute immensely to health and safety compliance in the construction industry.

However, compliance with OHS regulations is one of the management efforts to determine if it correlates with OSH performance.

Four types of requirements for ensuring compliance in an organization

'Static' requirements: requirements for parts of the organization that do not change often, such as requirements for a building (fire-proof doors, presence of a sprinkler system, etc.).

Technical requirements: requirements for technical measures and maintenance.

Performance and monitoring requirements: requirements that entail taking measurements (of concentrations, annual obligations or amounts), keeping records or drawing up reports (including reports, measurements and studies by third parties).

Organizational requirements: for matters such as training and instructing personnel (SCCM, 2012)

Idubor and Osiamoje (2013) opined that organizational requirement should paramount of which adequate OSH training and education will enhance the OSH performance e.g., compliance with OSH regulation. Other methods for guaranteeing compliance include:

A checklist which is gone through at defined intervals;

Frequent measuring, recording and reporting (these can be kept up to date in a register or overview of measurements, records and reports);

Laying down the method in procedures or instructions which are ensured by means of internal audits;

Translating requirements into action linked to officers and recording these actions once carried out (SCCM, 2012).

Smallwood (2010) posited that attitude is a key to understanding employees' behavior and prevention of on-site-job injuries. Hence, employees must have adequate training on safety programme (Schulz, 2004) and organisations must undergo a cultural change to filter any sort of attitudinal change that may occur to every employee (Schulz, 2004). Central to this culture is the feeling that safety is a top priority and nothing else. There will be improvement in H&S practices if attitudinal change is put under control. Christian, Bradley, Wallace and Burke (2009) were of the view that accident in the construction industry can be reduced through more sensitive or good safety behaviours of both employees and employers. Ineffective implementation of OSH will lead to bad safety behaviour. Moreover, OSH implementation requires employers to cater for the safety needs of their employers and employees (Labour and Human Resources Statistics, 2001-2005, 2009 in Christian et al., 2009).

4. Findings and Discussion

Results from the study revealed that varying impact on the employee's actions towards H&S compliance were observed by the experts from the sixteen indicator variables (Figure 1). Three attributes (ensure equipment /tools are in good condition before usage, ensure the use of personal protective equipment (PPE) and ensure proper positioning of tasks) were considered by the experts to have reached consensus with IQD cut-off (IQD ≤1) score. This score implies the measurement variables have very high impact (VHI: 9.00-10.00) on employees' safe acts towards H&S compliance and indicates strong consensus. Consensus was also reached on nine other measurement variables with IQD cut-off (IQD≥1.1≤2) score. The IQD score indicates good consensus for the nine measurement variables and the impact on H&S compliance was high (HI: 7.00-8.99). Four measurement variables reached consensus with IQD cut off (IQD≥2.1≤3) score, which indicates weak consensus on the measurement variables and impact on H&S was medium (MI:5.00-6.99). Using the median as a means of reaching consensus, fourteen (14) attributes were considered to have reached consensus, with the exception of two measurement variables (avoid annoyance and horseplay at the workplace and do not service equipment that is in operation) which did not reach consensus as shown in Figure 1.

From the impact ratings of the factors, findings revealed that 4 of the factors or measurement variables have a very high impact (VHI: 900-10.00), while 8 other factors or measurement variables have high impact (HI: 7.00-8.99). The remaining four other indicator variables or measurement variables have medium impact (Figure 1).

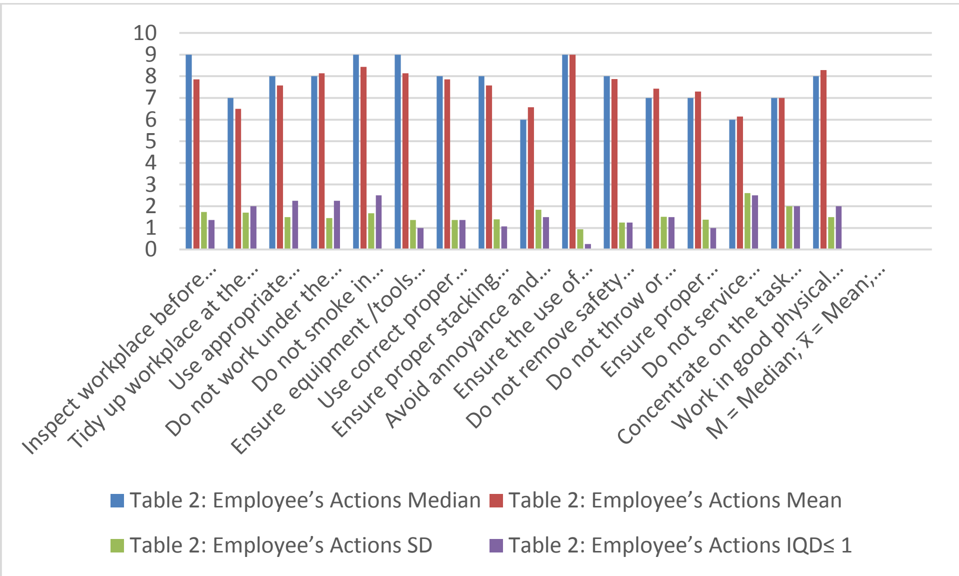

Figure 1: Safe Act of Workers

The measures of reliability, convergent and discriminant validity for each of the indicator variables or measurement variables realised through EFA (Figure 2) are discussed. Five items were realised at the end of the EFA (Figure 2). The corrected item-total correlation was greater than the suggested cut-off value of 0.30 suggesting that the items were good measures of the element and the Cronbach alpha was greater than 0.807 at 0.808 indicating acceptable internal reliability (Nanually and Bernstein, 1994). The Kaiser-Meyer-Olkin (KMO) of 0.886 with Bartlett's Test of Sphericity of p<0.000 were also obtained, indicating consistency with the recommended KMO cut off value of 0.70 and Bartlett's Test of Sphericity of p<0.05 suggested by Hair et al., (2010). These results suggested that factor analysis could be conducted with the data. The communality were also above 0.3 and the in Total Variance Explained fourteen (14) indicator variables or measurement variables were above 1.00. Eleven items (SAW 1-SAW 6 and SAW 11-SAW 15) were dropped during the EFA. The factor loadings for all items ranges between 0.5593 and 0.778 (Figure 2). The lower value of 0.5593 was greater than the recommended value of 0.40 as suggested by Field (2005) and Hair, Bush & Ortinau, 2002) for Confirmatory Factor Analysis (CFA) to be conducted on the measurement variables.

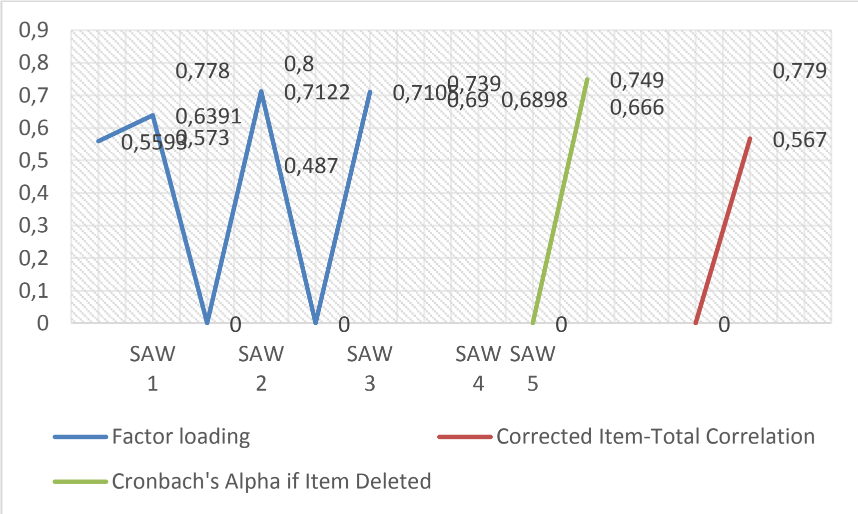

Figure 2: Employeee’s Actions

5. Conclusion and Further Research

The purpose of the study was to examine employee’s actions towards health and safety compliance in construction. Measurement variables were considered by the experts to have high impact on employee’s actions. IQD was used to reach consensus for the study with varying impacts. The median ranging from (7.00-10.00) was also achieved in reaching consensus. Further Exploratory Factor Analysis (EFA) revealed that five indicator variables were found to be the determinant of H&S compliance in relation to employee’s actions. It can be concluded from the findings that employee’s actions are very significant in deriving health and safety compliance in the construction industry. Further research will be conducted using large sample to evaluate the validity of the factors among large construction firms.

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Mechanical Safety and Survivability of Buildings and Building Structures under Different Loading Types and Impacts

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Abstract

Modern construction sites are characterized by rapid pace and complicated organization of work processes. One of the important problems of a construction site is the human safety. The paper contains a categorization of human hazards during construction activities and an analysis of main causes of accidents in buildings and at construction sites. Together with general definitions of safety the paper reviews some new research trends in the field of mechanical safety and structural survivability of buildings and structures under different loads and impacts, including regular and accidental types of loading. It is shown that up-dating of safety regulations should mean not only the clarification of new terminology adopted in building codes and regulations on structural safety, but also supplementation of the regulations with sufficiently justified and experimentally verified provisions that should regulate the safety of buildings and structures under design and beyond-design basis loads and actions.

Keywords: construction site, human safety, mechanical safety of buildings, structural survivability.

1. Introduction

Human beings exist in an environment that is potentially hazardous for their life activity. Yet, living environment itself is also endangered by a number of factors that can be ranged according to their global risk level. First, it is the position of Earth in the Universe, then, the different natural disasters like earthquakes, cyclones, avalanches, floods, hurricanes and, last but not least, military threats and the Earth's current condition formed due to technical activity of people. Many astronomic discoveries that were made during the last decade have also revealed new serious threats and risks for human existence.

The rate of human influence on the environment increased in the middle of the 19th century when industrial revolution started. By invading into nature and inventing new technologies people built up their artificial environment, or technosphere.

The philosophers of the past used to think that the development of science and technological progress would foster human dominance over nature. Population was expanding with urban residents increasing very quickly. It caused a growth of urban areas, including roads and disposal fields, which resulted in the degradation of nature and cut down natural habitat realm of many plants and animals.

That is why in the early 20th century new wave of thinkers critically reviewed the progress of technology that stopped being just a human tool and turned into an individual activity sphere that threatened natural environment and contributed to human extinction. In the second half of the 20th century the changes in the environment developed to such extend that they jeopardized the human beings either directly or indirectly and actually made their activity. A number of serious challenges emerged including radioactive waste disposal, climate changes resulting from atmosphere pollution and flooding of territories as a result of the construction of hydroelectric power them fall prey to plants. Now many biological interactions are replaced by the processes of physical and chemical

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interaction, which have a negative impact on people and natural environment. In fact we are talking about human safety under specific conditions. For biological systems safety quality is defined as survival rate [1].

2. Safety in living environment

Humanity exists in continuous interaction with its living environment in a constant exchange of substances, energy or information. Natural environment provides our planet with solar energy, flora and fauna. Technosphere provides artificially generated energy and various raw materials, supplies products and human resources, produces waste. Social environment is an integral system of material, economic, social, political and cultural conditions for existence, formation and activities of individuals and social groups [2, 3]. Depending on the size of the mentioned types of energies, substances and social conditions it is possible to trace down several typical interaction states in the system "human being – living environment" (Fig.1):

comfortable state with best conditions for work and rest, preservation of human health and environment;

admissible state without negative impact on human health, but with a feeling of discomfort and decreased efficiency of human activity;

harmful state with negative impact on human health, which causes human diseases and environmental degradation;

hazardous state which causes disastrous effects in natural environment and results in lethal outcome.

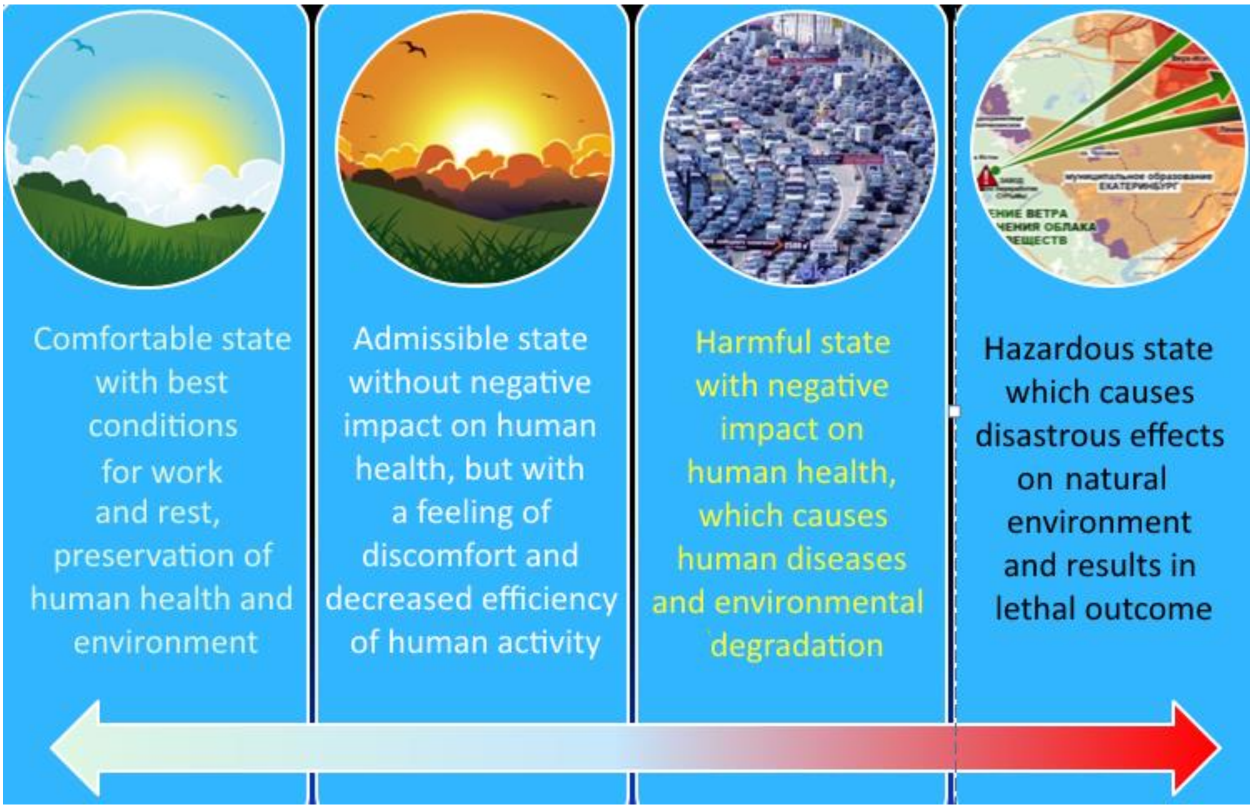


Figure 1. Levels of interaction with living environment

Two of the above mentioned states, harmful and hazardous ones, are inacceptable for human activity processes and natural environment preservation.

These two states are inseparably related to such notions as an emergency event (EE) and an emergency situation (ES).

Emergency event is a short-term incident that has a significant negative impact on people, natural and material resources. Emergency events include major accidents, catastrophes and natural disasters.

Emergency situation is characterized as conditions that have arisen as a consequence of an accident, a hazardous natural phenomenon or other acts on a certain territory or water area, and can endanger human life or health, cause material damage and deteriorate natural environment.

Urban habitat is characterized by significant amount of various modes of transport and intensive traffic, varied development, various industries, including potentially hazardous ones, and high concentration of utilities per unit area.

A city has some areas with elevated risk factors like concourse zones or locations in close vicinity to potentially hazardous facilities. In order to get protected against everyday natural risks people use dwellings, clothing, ventilation, heating and conditioning systems, and artificial lightening.

The list of negative factors is long. First of all it includes air polluted by industrial emissions, natural gas combustion products and automobile exhaust gases, discharges of incinerators and emissions of thermal or nuclear power plants. Then it includes contaminated waters, noise and vibration, electromagnetic fields, poor lightening, monotone activities and hard physical labor.

Location areas of main traffic arteries, radio or television transmitters, as well as the use of industrial or domestic appliances pose serious technogenic risks for people in case of their presence. Human errors are considered to be the main cause of about 80% of plane crashes; 60-80% of road accidents and over 60% of accidents at high-risk industrial facilities.

As life activity of people is potentially dangerous, the current world practice has turned down the idea of absolute safety in favor of risk concept [4,5,6]. Risk is the probability of a potentially dangerous event in a dangerous situation (Fig. 2).

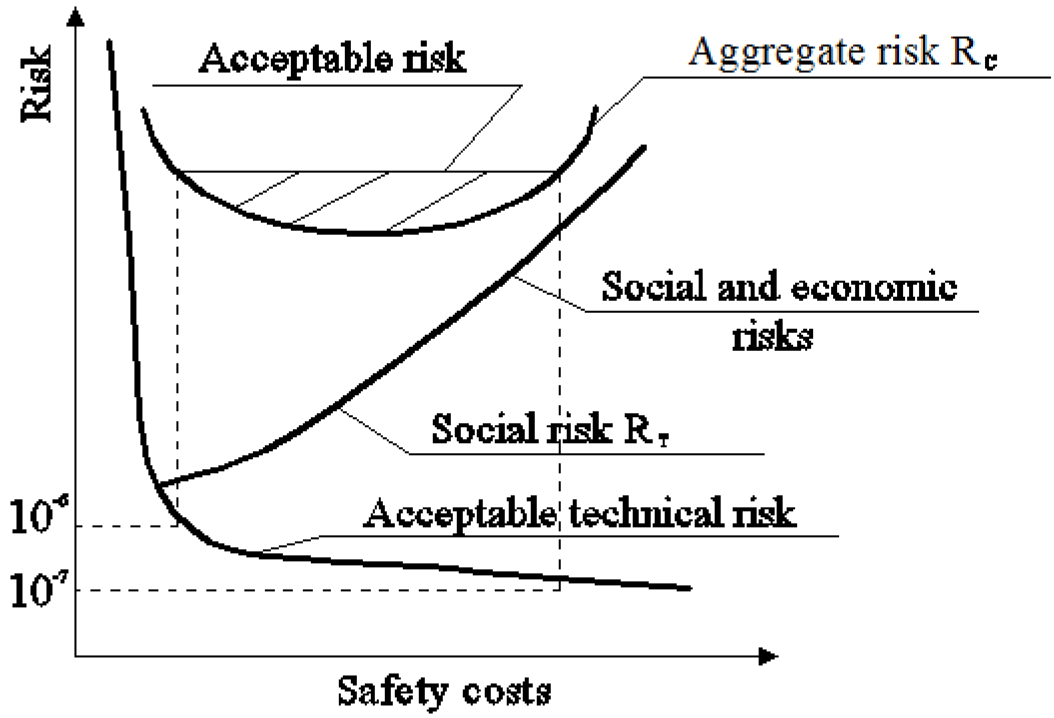


Figure 2. Acceptable risk concept

The analysis of human life activity shows that it is impossible to reach a zero risk level in any sphere. The quantitative assessment of the probability of a negative effect on humans is expressed as risk of harm or damage. When risk is acceptable the protection measures are able to ensure a certain preset safety rate, i.e. this is a compromise between safety level and possibilities to reach it. When investment into safety increases, new equipment and new production technologies are developed, hence technological risk is reduced, however, at the same time common wealth may go down, which will cause social and economic risks. Aggregate risk is minimal if investments into technical and social spheres are in due proportion. This factor should be considered when identifying a risk that the society should reckon with.

Objective need of an individual and the society in security and protection against hazards has almost reached its maximum. Death rate is high in many countries as a result of bad environment, significant injury rate, heavy alcohol drinking and diseases.

In Russia these factors are aggravated by high urbanization rate. It causes a growth of the disabled and consequently leads to serious challenges that have to be met in order to ensure safety and accessible environment for such social groups [7].

One of the most important strategic tasks of the Russian Government is to ensure safety of water supply and sewage systems [8]. In today's Russia the total yearly amount of water supply is over 18 bln m^3, however about

30 million people have no access to centralized water supply systems. At the same time there is a degrading trend in the state of central water supply sources and in sanitary and epidemiological condition of water supply lines. (Tables 1 and 2).

Table1 – Current condition of central water supply sources

Indicator	2011		2012		2013		Gain rate in per cent compared with 2011,%
	total, pieces.	share, %	total, pieces	share, %	total, pieces	share, %	
Sources that do not meet sanitary and epidemiological norms	16 583	16,2	16 103	15,8	16 020	15,8	-2,5

Table 2 – Water supply lines that fail to meet sanitary and epidemiological standards

Indicator	2011		2012		2013		Gain rate in per cent compared with 2011
	total, pieces	share %	total, pieces	share %	total, pieces	share %	
Water supply lines that do not meet sanitary and epidemiological norms due to the lack of	13 099	19,0	12 801	18,4	11 927	17,8	-6,2
- sanitary protection zones	7 445	56,8	7 315	57,1	6 350	53,2	-6,3
- water treatment facilities	4 832	36,9	4 600	35,9	4 518	33,9	-5,7
- water disinfection means	1 777	13,6	1 711	13,4	1 645	13,8	1,4

Treated sewage waters can still contain heavy metals, which can be explained by discharges of wastewater from industrial facilities.

Therefore the development of environmentally friendly water treatment systems together with reliable water supply and water drainage lines, which should meet up-to-date sanitary standards, is a top priority.

Air pollution with suspended particles, nitrogen dioxide, benzapyrene, benzene hydrocarbons is registered in 76 subjects of the Russian Federation. In 13 regions of the country the air pollution level is really high [9].

There are up to 100 bln tons of waste accumulated on dumps, waste grounds and in waste storages, among them about 1.5 bln tons is toxic waste [10]. Every year about 2 thousand hectares of lands, including agricultural areas, are allocated for solid waste storage purpose. Research Institute of Construction Physics of the Russian Academy of Architecture and Construction Sciences together with Central Research Institute of Ferrous Metallurgy have developed energy saving environmentally friendly technologies of processing bulky waste of metallurgical and power production industries. The waste is processed into composite astringents and aggregates that can be used in the production of light and heavy concretes. The research on this solution has been performed within the framework of the Federal Target Program “Housing”. Analytical data given in Table 3 shows that the share of processed bulky industrial waste in the production of cements is about 50% and in the production of dense and porous aggregates is about 20%.

Table 3 – The structure of bulky technogenic waste and its processing products that are recommended for use in the manufacture of light and heavy concretes (as of January 01, 2015). Source: Research Institute of Construction Physics

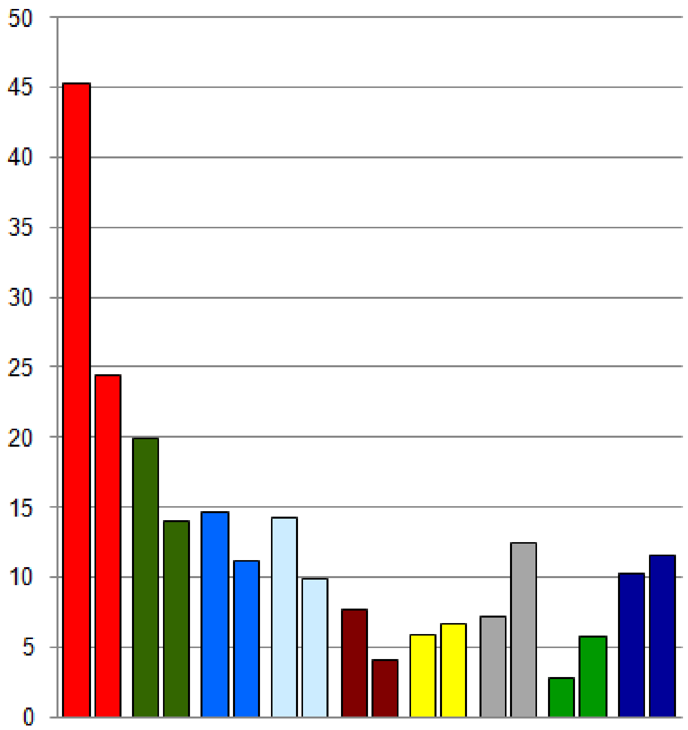
Types of technogenic waste	Waste production volume, mln t/year	Potential volume of processed materials, per year		
		Portland blast-furnace cement, composite astringents, mln	Dense aggregates for heavy concretes, mln m3	Porous aggregates for light concretes, mln m3
1	2	3	4	5
Ferrous and non-ferrous metallurgy				
1. Blast-furnace melts cast iron production waste	34,0	28,0	4,5	14,5
2. Granulated slags – copper and nickel production waste	12,5	–	11,3	–
3. Cast slags – nickel production waste	2,2	–	1,8	–
4. Bauxite sludge – aluminous production waste	2,5	4,2	–	1,2
Power production				
5. TPP slag and cinder	12,5	6,0	0,8	18,2
6. Coal enrichment waste	12,0	–	–	15,6
Total:	75,7	38,2	18,4	49,5

As for the causes of accidents on construction sites, as seen in Figures 3 and 4, more than a quarter of all accidents occur because of the poor quality of construction and installation work, a quarter of accidents occur due to poor operation of the facilities and about the same quantity of accidents occurs due to the poor quality of materials and structures. Poor quality of design work is the cause of a tenth of the accidents.

Economic crises contribute to the growth of accidents due to the reduction of so called secondary works like heat and waterproof insulation or anticorrosion coating works or due to interruptions in the construction works without proper mothballing.

The reliability concept is widely applied in the safety analysis of technical solutions. [11, 12]. Reliability can be described as an appropriate performance of a facility under specified conditions of operation, maintenance, storage and transportation. Reliability is an inherent feature of an object. It is revealed through the interaction of this object with other objects within a technical system and its relations to external environment. As reliability is a complex feature it has to be assessed on the basis of individual properties such as safety margin, durability, maintainability and integrity.

To assess the safety of a technical system, its reliability analysis should be supplemented by the review of possible consequences of its failure. It should be done in order to assess the possibility and extend of damage for people and equipment, i.e. it is necessary to assess the risk. Except general safety there is also mechanical safety, which is ensured load-carrying capacity of a structure. Effective technical regulations [13] introduce a new design condition – a design accident event which has a low probability of occurrence and a short-term period of action, but may be significant in terms of the consequences of reaching the limiting states that can develop thereof. In fact the new design condition concerns the survivability of structural elements in emergency situations [14, 15, 16].



№, color		Facility type	2013		2014	
			Number of emergences	Share, %	Number of emergences	Share, %
1		Residential buildings	177	45,3	59	24,4
2		Public buildings and concourse areas (institutions, schools, hospitals, sports facilities, stations, shopping centers, churches, etc.)	78	19,9	34	14,0
3		Buildings under construction, renovation or maintenance	57	14,6	27	11,2
4		Other building structures (fences, railings, parkings, stacks, water towers)	56	14,3	24	9,9
5		Non-operating facilities (abandoned)	30	7,7	10	4,1
6		Industrial buildings	23	5,9	16	6,6
7		Lifting mechanisms (cranes, elevators)	28	7,2	30	12,4
8		Bridges	11	2,8	14	5,8
9		Grounds	40	10,2	28	11,6

Figure 3. Accidents at all types of facilities in 2013-2014

Type of facility	Zone of specific risk	Color	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Residential buildings	1		*22*	*31*	*42*	*38*	*29*	*35*	*61*	*101*	*112*	*177*	*59*
Public buildings and concourse areas	2		*19*	*19*	*38*	*24*	*18*	*19*	*43*	*49*	*52*	*78*	*34*
Objects under construction or renovation	3		*12*	*15*	*20*	*27*	*22*	*21*	*36*	*26*	*37*	*57*	*27*
Decommissioned facilities			*6*	*7*	*13*	*15*	*11*	*8*	*23*	*25*	*30*	*30*	*10*
Industrial buildings			*12*	*13*	*15*	*9*	*10*	*10*	*28*	*24*	*34*	*23*	*16*

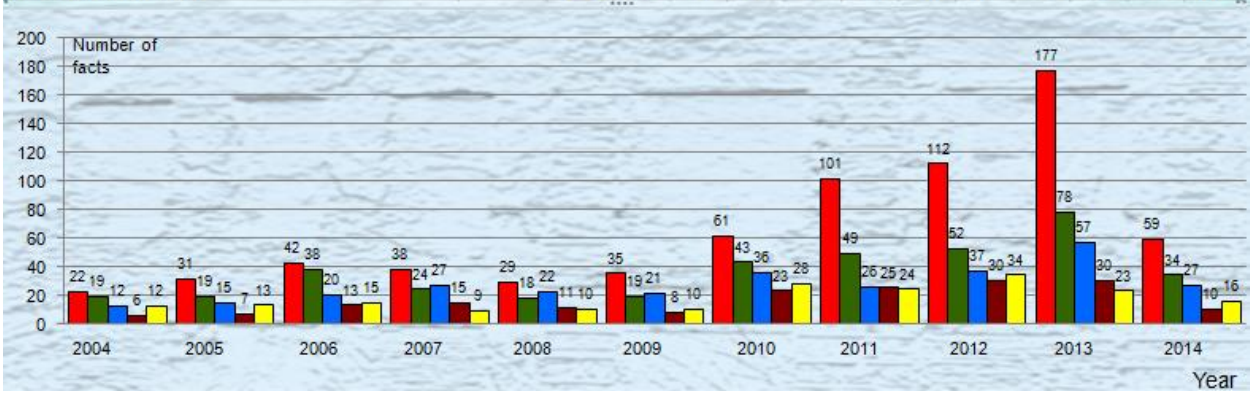


Figure 4. Building collapse accidents in 2004-2014

Progressive or avalanche-like structural failure is a chain reaction to a local disproportionate initial failure of a structural element, which results not only in a disproportionate collapse of the structure, but also in a disproportionate shortening life of operation and in damage. Such event can be initiated by one of numerous accident factors like accidental explosion, fire, design or construction error, or a terrorist act. Modern structures have a restricted load-carrying margin that is insufficient to withstand such accidental impacts. There is neither generally accepted scientific base nor design practice that can ensure a complete integrity of a structure in an emergency situation when design loads can be combined with accidental impacts. Obviously, methods and technologies should be developed to enhance resistive capacity of the existing buildings and their adaptability to progressive collapse. Modern effective calculation systems are able to determine the response of a structure to accidental dynamic loads. However these results have to be verified by large-scale experimental data. Of accident structural failures people have accumulated some knowledge about vulnerability of structural systems. The accumulated data can be used to build up a proven model of plastic work of buildings and structural elements under accidental impacts.

Probability and potential consequences of accidental impacts and progressive collapse should be clearly stated in the relevant standards and regulations and should become an integral part of the design process. Standards and regulations should basically define that the consideration of a progressive collapse event is an obligatory design requirement; it should be taken into account irrelevantly of the initiating event type, i.e. whether the initiator is an "accidental" or a "regular" loading.

The risk of a progressive collapse cannot be eliminated completely. Designers should be responsible for justifying the measures designed to minimize the risk of a progressive collapse. Design engineers should understand how complex this problem is and should consider different variants at the stage of conceptual project planning. Moreover the design engineer should inform the developers, architects, building owners and residents about possible consequences of emergences.

The safety of social and living environment largely depends on the safety of buildings and structures. In Russia the safety of environment has always been ensured by the system of national regulations that demand obligatory use of State Standards (GOSTs) and Construction norms and regulations (SNiPs). Recently there has been an attempt to make the use of standards optional. In 2003 the voluntary use of standards was fixed in Russian federal law on technical regulations. In the period when the use of SNiPs was obligatory there were no accidents, but those regulations were heavily criticized as "hindering the technological progress". Russian Academy of Architecture and Construction Sciences together with numerous construction organizations put a lot of effort to prove the necessity of mandatory use of SNiPs. Finally, in 2009 the technical regulations on the safety of buildings and facilities were adopted in the status of the Russian Federation Federal Law No. 384-FZ. It includes Article 5.1 which concerns specific regulations for the safety of buildings and structures, outlines specific features of technical regulations in construction industry and fixes obligatory implementation of a certain group of construction norms and regulations.

Recently Russian Government has adopted a revised version of the List of standards and regulations that must be used in order to comply with the requirements of the federal law on technical regulations. The adopted list is not free from the mistakes that used to be in the former document, as it is also divided into two sections, with one part comprising mandatory regulatory documents and the other one containing optional regulations. Meanwhile the optional use is not regulated by any legal acts. Moreover, optional regulations and standards in Russia cannot be used as basis for expertise of design documentation or for building inspections, etc.

More detailed review of the List shows that, evidently, its authors' goal was rather not to register all necessary documents that contain safety requirements covering every aspect of the technical regulations on the safety of buildings and facilities, but to reduce the number of obligatory documents. As a result the new List contains 76 documents, which is by 15 items less than was in the previous list. Only two GOSTs were included into the List. Yet, even the main standard GOST 54257 "Reliability of building structures and foundations" was seriously revised: its two sections (Section 3.1 "Reliability of building structures" and Section 3.2 "Durability of building structures and foundations") were excluded from the list of obligatory documents and transferred into optional use. GOST standards that regulate the methods of building materials testing were included neither into the obligatory nor into optional sections. However, for designers, building inspectors and building engineers, testing regulations predetermine a similar understanding of mechanical and other properties of building materials. Such properties should be clearly specified and should not differ depending on a test lab. All rules of conducting construction operations have been left outside the List, though they logically should have been included into the list of obligatory standards as they have direct influence on the safety of buildings and construction elements. Experts from the Russian Academy of Architecture and Construction Sciences think that the technical regulations on the safety of buildings and facilities should be supplemented with a special section explaining basic principles of optional use.

Risk factors in industry, urban environment and individual dwellings usually have a prolonged effect, so it is necessary to monitor living environment continuously. It can be achieved by means of monitoring systems that register all changes in the environment and are able to generate alarm signals in case of deteriorating conditions. There is also a need to make electronic categorization certificates for all industrial and social buildings; the most important construction objects, construction elements and parts of buildings should be regularly inspected visually with registration of their current condition.

Figure 5. State information strategy is to protect environment against ourselves

The basis of city management is safety built on knowledge which includes professionalism, information, the development of proposals to eliminate the factors hindering the development [3]. In this regard, the state information strategy should include the following tasks: to regularly inform the public about toxic releases into the environment, to inform workers about the negative factors of production and their impact on health, to inform about the methods and means of protection against hazards. Protective measures to prevent or limit the identified hazardous conditions should include the introduction of special instructions for personnel (Figure 5).

3. Conclusions

For many centuries people have been developing technologies to protect themselves against natural hazards. As a result they have created technological risk factors related to production processes and everyday use of engineering means and technologies. In a modern city all challenges are lying in between two extremes: destruction of nature and degradation of the human being.

Today, when human activity has become global, an inadequate assessment of its consequences can cause disasters. In this situation urban future forecasts have become even more important. If in the past a forecast could be made on the basis of analogies and approximations, today we need extensive scientific research data and computer modeling.

Investigation of human life, cognition and activity is always related to uncertainty: people usually know much less than they would like to know. However uncertainty plays a very important role, as it prepares us for taking unexpected decisions.

Uncertainty can be surmounted by making hypothesis, or by creating images, which is a more frequent case. That is why many discoverers are artists, architects or poets.

People believe that their progress cannot be stopped by some barriers. Does it mean that human capabilities are unlimited, or does it mean that the humankind has not yet realized that people have reached cognition limits and no further development is possible? People are never satisfied by nature, especially considering that it is limited to their habitat. If in nature the properties of matter are set by nature itself, in human civilization people use natural resources to get some useful properties that have never existed in nature. These new properties sometimes produce unplanned effects that may run into an uncontrolled process of interaction with nature and even may conflict with natural properties or with the properties of a human being.

Safe living environment does not just mean the absence of any hazard or risk of loss of life or assets, first of all it means the feeling of being safe, secured and protected and that there is no danger. To reach this goal is the objective, challenge and main meaning of profession of a builder.

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An Analysis of Problems with Current Indicators for Evaluating Carbon Performance in the Construction Industry

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Abstract

"Low-carbon" is well acknowledged as one of the key factors contributing to sustainable urban development, and also an effective approach for tackling climate change. Since the building sector accounts for a high proportion of carbon emissions, the construction is regarded as one of the most potential industry for reducing carbon emissions. However, there is no standardized indicator to measure carbon performance in the construction industry. As a result, the choice of various indicators may result in significantly different carbon performances which determine whether an industry is considered truly "low carbon". In this paper, the current indicators for assessing carbon performance in the construction industry are reviewed. The pros and cons of the current indicators are also highlighted. The problems of using the current indicators are discussed, and these problems are often related to accuracy of indicator, data availability and definitions of specific terms. Suggestions are made to focus on carbon emissions at building operation stage first as it accounts for a significant amount of carbon emissions during the whole building life-cycle. It should be highlighted that embodied emissions of buildings are also important during the whole building life-cycle. However, due to the challenges in data acquisition for calculating embodied emissions, attention should be paid more to the operational stage first as smart meters can be used to facilitate data collection processes. The findings provide clues for industry practitioners to develop an indicator which is more practical in use to assess carbon performance in the construction industry.

Keywords: carbon emissions, low-carbon performance, indicators, construction industry

1. Introduction

Reducing carbon emissions in all sectors and the planning of low carbon cities have been regarded as a solution to tackle climate change. It is well known that the building sector is responsible for a large proportion of carbon emissions [1]. A number of studies indicated that buildings consume more than 40% of global energy and account for 36% of carbon emissions [2]. In addition, the construction of buildings consumes significant amounts of raw materials (e.g. 40% of stone, sand and gravel, 25% of the timber and 16% of the water in the world) [3]. Given the above figures, the building sector has great potential for significantly reducing carbon emissions. The carbon emissions in the construction industry mainly come from the construction process and its supply chain from emissions embodied in construction materials [4]. The industry produces substantial on-site emissions from electricity and fuel use, transporting workers, materials, deliveries, and waste [5].

The urgency to reduce the current level of carbon emissions through innovative technology in design and use of materials, regulations and setting energy and carbon rating standards has been increasingly advocated. However, a comprehensive and robust development of a set of low-carbon indicators, and in particular, a method for calculating carbon emissions is still lacking a consensus. Thus, it is difficult to determine whether a sub-sector in the construction industry is 'low carbon'. This paper aims to review the current indicators for assessing carbon performance in the construction industry, and provide future directions to develop a low-carbon indicator. The paper first discusses the pros and cons of current indicators. After that, the problems of using these indicators are highlighted. Future directions are also suggested to develop an indicator which is more practical in use to assess carbon performance in the construction industry.

2. Current Indicators

Indicators are defined as a tool for visualizing the current conditions in complex systems by expressing those conditions in numerical form, for example, environmental indicators for environmental systems. Low-carbon indicators play an important role in tracking progress towards meeting the increasingly urgent goal of a low-carbon future. Low-carbon indicators can be used by national, regional and local governments, non-governmental organizations and research institutions to measure the status of low-carbon development and outcomes of climate change policies. The indicators also enables policy makers to benchmark targets, strategies and policies to support policy improvements. In general, the current indicators for assessing carbon performance can be classified into two types, namely, macro-level indicators and micro-level indicators. Table 1 shows the current carbon indicators in the construction industry.

Table 1: Pros and cons analysis of current carbon indicators in the construction industry.

Indicator(s)		Pros	Cons	Observations
Macro-level	Economic-based indicators	Provide a quick comparison among cities, regions, and province	Ignore the differences of economic structure	Commonly used in the international level
	Population-based indicators	Provide a quick comparison among cities, regions, and province	Not consider migrant/transient populations	May lead to over-accounting of energy use per capita
Micro-level	CO_2 emissions in the construction of a single building	Focus on carbon emissions during the construction and demolition stage	Not consider the operation stage	No standard method to calculate carbon emissions at different stages
	Life-cycle CO_2 emissions in a single building	Consider carbon emissions during the operation stage	Involve complicated calculations	No standard method to calculate carbon emissions at different stages
	Average CO_2 emissions per working area per year	Eliminate the impact of different working areas on CO_2 emissions	Difficult to determine the period of construction and operation accurately in advance	Able to compare the level of carbon emissions with different buildings
	Life-cycle carbon efficiency	Provide a linkage between life-cycle carbon emission and value creation of buildings	Difficult to define life-cycle values for various buildings	The concept of life-cycle carbon efficiency is not widely adopted

2.1. *Macro-level indicators*

2.1.1. Macro-level economic-based indicators

For macro-level indicators, it can be further divided into two types of indicators, namely macro-level economic-based indicators and macro-level population-based indicators [4]. Macro level economic-based indicators are the indicator based on CO_2 emissions per unit of GDP. This economic-based indicator comprises two components: (1)

energy intensity, defined as the amount of energy consumed per unit of economic activity; and (2) carbon intensity of energy supply, defined as the amount of carbon emitted per unit of energy [6]. It is worth noting that there is a difference between final energy and primary energy when constructing this indicator. Final energy, or end-use energy, accounts for energy delivered at the end-use sites, but it does not consider energy loss during transmission and distribution (T&D) and electricity generation efficiency. Primary energy is the sum of final energy and energy consumed during the T&D of electricity and the generation.

2.1.2. Macro-level population-based indicators

Compared with macro-level economic-based indicators, macro-level population-based indicators use population as the denominator instead of GDP. The main propose of using these macro-level indictors is to compare the level of carbon emissions among cities, regions, and provinces.

2.2. *Micro-level indicators*

Unlike macro-level indicators which focus on the level of carbon emissions among cities, regions, and provinces, micro-level indicators emphasize the level of carbon emissions in a single building. In general, there are four types of micro-level indicator for assessing carbon performance in the construction industry.

2.2.1. CO_2 emissions in the construction of a single building

The total amount of CO_2 emissions in the construction of a single building can be used as an indicator to compare carbon performance with different buildings. This indicator only focuses on four major sources of CO_2 emissions in building construction: (1) manufacture and transportation of building materials; (2) energy consumption of construction equipment; (3) energy consumption of processing resources; and (4) disposal of construction waste.

2.2.2. Life-cycle CO_2 emissions in a single building

Unlike the above indicator, a life-cycle CO_2 emission in a single building is an indicator which calculates the CO_2 emissions during the whole building life cycle. Apart from the stage of material production & transportation, construction as well as demolition and waste, this indicator also includes CO_2 emissions at the stage of building operation and maintenance. The findings of existing literature show that the building operation stage accounts for approximately 80-90% of the total CO_2 emissions, whilst the construction stage only constitutes 8-20% [7].

2.2.3. Average CO_2 emissions per working area per year

The main drawback of using total CO_2 emissions as an indicator is that no conclusion can be simply drawn when comparing their total CO_2 emissions with different buildings. This is because the amount of CO_2 emissions for a building not only depends on construction methods and use of construction materials, but also relates to building areas and construction period. Therefore, another carbon indicator, defined as average CO_2 emissions per working area per year, is developed to provide a more practical comparison between different buildings. Peng [8] calculated the average CO_2 emissions per working area per year for different stages of an office building in China, and found that although the operation stage accounts for approximately 85% of the total CO_2 emissions, the average CO_2 emissions per working area per year of construction stage is much higher than that of the operation stage.

2.2.4. Life-cycle carbon efficiency

Life-cycle carbon efficiency is defined as life-cycle values per carbon emissions of building. Li, Chen [2] used this indicator to calculate the life-cycle carbon efficiency of one residential building in Hong Kong. In principle, there can be different definitions for life-cycle values. For example, the value of residential building can be related to its sale price. In the studies of Li et al., the life-cycle value is the product of its service life span and building space in area size (m^2) or by the volume in cubic size (m^3). The main advantage of this indicator is that it provides a linkage between life-cycle carbon emission and value creation of buildings.

3. Problems with current indicators

Since there is no standardized indicator to measure carbon performance in the construction industry, the choice of various indicators may result in different carbon performance for the same building. Other problems of current indicator will be discussed and Table 2 lists the problems of current indicators for evaluating carbon performance in the construction industry.

3.1. *Macro-level indicators*

Price, Zhou [4] discussed the issues with the macro-level indicators and summarized into three aspects. First, the macro-level indicators do not accurately reflect end-use energy or carbon intensities because they are generated using a top-down approach. Second, the official population data often exclude the impact of migrant or transient populations, and this may result in over-estimation of energy use per capita in cities, especially for those cities with large migrant populations. Third, different countries may have their own definitions for end-use energy and use different data sources, making cross-country comparisons inaccurate.

3.2. *Micro-level indicators*

Unlike macro-level indicators, micro-level indicators are used to compare carbon emissions between different single buildings. This type of indicator allows decision makers to analyze carbon emissions at various stages of building life-cycle and benchmark targets on the level of carbon emissions for different types of buildings. However, there are several issues when using the micro-level indicators.

To-date, there is no agreement on the calculation method of carbon emissions at various stages of the whole building life-cycle. For example, there are several methods for calculating carbon emissions at construction stage. Peng [8] adopted the comprehensive method for calculating carbon emissions at construction stage. This method not only includes the CO_2 emissions produced by the operation of construction equipment and office devices, but also by various construction crafts and horizontal transportation. However, this method heavily lies on the energy data which is commonly unavailable in the construction industry. In the Li, Chen [2] calculation method, construction activities are divided more specifically into four major types, including excavation and removal earthwork, grading earthwork, site lighting and crane handling. The advantage of Li et al method is that it is easier to determine the level of those construction activities since they are in the unit of ton, m^3 or m^2.

Data availability and quality are also the issue for calculating carbon emissions at specific stages. For example, assumptions are usually made to evaluate carbon emissions at demolition stage due to lack of actual data. The typical approach is to use the data from other countries to estimate the amount of diesel oil per m2 during the demolition stage. Apart from that, it is often assumed that the end-of-life materials will be landfilled at the end. However, there are other alternatives to disposal those materials, such as incineration and recycling. Therefore, those assumptions may result in inaccurate results of carbon emissions for buildings. In addition, Peng [8] indicated that not all the data is classified as high quality data since the development of life-cycle assessment database in construction processes involves many different data sources, underpinning the accuracy of results.

For life-cycle carbon efficiency indicators, difficulties are found in defining life-cycle values. Ideally, life-cycle values should be related to monetary terms which make the indicator easily comparable. However, it is found that the sale price of buildings may not be a suitable factor to determine life-cycle values since the sale price is easily influenced by outside factors such as inflation, market speculation and currency policy. Although Li, Chen [2] defined the life-cycle value for residential buildings, there is still lacking a consensus on the definition of life-cycle values for other types of building such as hotels and office buildings.

Table 2: Problems with current indicators for evaluating carbon performance in the construction industry

Indicator(s)	Problems
Macro-level indicators	Not accurately reflect end-use energy or carbon intensities
	Exclude the impact of migrant or transient populations in the official database
	Have their own definitions for end-use energy in different countries
	Use different data sources
Micro-level indicators	No agreement on the calculation method of carbon emissions at various stages of the whole building life-cycle
	Lack of data to calculate carbon emissions
	Poor quality of empirical data
	Difficult to define life-cycle values for other types of building

4. Future directions

4.1. *Development of low carbon indicator for construction industry*

As discussed in Section 3, there are several problems in the current indicators (both macro-level and micro-level indicators). It is concluded that the problems are related to accuracy of indicator, data availability and definitions of specific terms. Therefore, there is a need to develop an indicator which is more practical in use to assess carbon performance in the construction industry. Since the main purpose of using indicators in the construction industry is to compare carbon performance between different buildings, instead of different cities or regions, the micro-level indicators are more suitable than the macro-level indicators. Due to data availability, the indicator may not be accurate enough to calculate carbon emissions at each stage of the building life-cycle in details. However, the indicator can provide a general picture for construction practitioners to determine whether the proposed building is a low-carbon building or not. For Hong Kong construction industry, it is suggested that the micro-level indicator "average CO2 emissions per working area per year" will be more suitable for use since it can make a simple comparison between buildings based on the value of indicator. To ensure that this indicator can be further adopted in the construction industry, the calculation method should be standardized and relevant organizations should develop their own life-cycle assessment database.

4.2. *Focus on operation stage*

A number of studies indicated that building operation stage accounts for a significant amount of carbon emissions to meet various energy needs such as heating, ventilation, and air conditioning (HVAC), water heating, lighting, office equipment and telecommunications [8]. Islam, Jollands [9] highlighted that the ratio of carbon emissions of construction to operation stages is over 50%. Ramesh, Prakash [10] found that up to 30 % of the embodied energy is attributed from construction in commercial buildings. Although the actual carbon emissions at the operational stage vary from different building types, climatic conditions and thermal comfort requirements, considerable agreement is still observed that attention should be paid on the operational stage to reduce carbon emissions due to the large potential in carbon reduction in existing buildings [11]. The common examples of improving building energy performance include installation of higher insulation on external walls and roofs, optimization of HVAC systems, as well as using high thermal performance windows [12].

With the considerations of the above situation, a carbon indicator which focuses on the operational stage should be first developed. Due to the technological advancement (e.g. adoption of smart meters in buildings), the data acquisition for calculating embodied emissions at the operational stage becomes more convenient and reliable. A carbon audit report regarding the central building services systems can be generated automatically if the sufficient smart meters are installed in buildings. It should be noted that this study does not suggest fully neglecting the embodied emissions of buildings. However, tremendous efforts are needed in order to collect all necessary data for calculating embodied emissions of buildings at the construction stage. In addition, no standardised method to conduct a life-cycle assessment for buildings is yet developed. Without the standardisation of calculation method, it is difficult to develop an effective carbon indicator which can be used for comparisons with different types of buildings.

5. Conclusions

In this paper, a review of the current indicators for assessing carbon performance in the construction industry is conducted. It is found that there is no standardized indicator to measure carbon performance in the construction industry. As a result, the choice of various indicators may result in significantly different carbon performances for the same building. In addition, the problems of using the current indicators are often related to accuracy of indicator, data availability and definitions of specific terms. Therefore, there is a need to develop an indicator which is more practical in use to assess carbon performance in the construction industry. Suggestions are made to focus on carbon emissions at the building operation stage first as it accounts for a significant amount of carbon emissions during the whole building life-cycle. It should be noted that embodied emissions of buildings are also important. However, due to the challenges in data acquisition for calculating embodied emissions, attention should be paid more to the operational stage first as smart meters can be used to facilitate data collection processes. The findings provide clues for industry practitioners to develop a more practical indicator, and thereby improve overall carbon efficiency in the construction industry.

Acknowledgements

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Evaluation of Bridges Life Cycle Costs

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Abstract

The paper presents the evaluation method for bridge alternatives assessment. The selection was chosen multicriteria decision making method, where not only criterion cost. Faculty of Civil Engineering deals with the life-cycle costs, and in this area offers a tool to assess the LCC for bridges. In addition, the principle of self-evaluation is further described in more detail above tool designed for skilled setting and evaluation of LCC. Furthermore, the presented method takes into consideration the Czech legislation: Act No. 137/2006 Sb - Public Procurement, specifically §78 - Evaluation Criteria, which states that the main selection criteria for all bids must be either the economic benefits of the proposed bid or the lowest bid cost. The above noted indicates that the LCC may be incorporated into such tendering as part of the economic benefits evaluation. In order to calculate the LCC it is essential to establish a transparent model, which will unambiguously evaluate the proposed bids from the cost-effectiveness point of view. This paper presents the application "Bridgepass", which incorporates pre-defined requirements for the calculation of the LCC, and offers pre-determined weighting criteria for evaluating the proposed solutions of bridges and estimating the overall value of each bid.

Keywords: bridges, Bridgepass, Life Cycle Costs, evaluation, tender.

1. Introduction

The main aim of this paper is to present a method that includes for operational cost considerations within the tendering process of projects, under the Design and Build procurement route, and by doing so to assist in selecting the most effective bid / option. Furthermore, the presented method takes into consideration the Czech legislation: Act No. 137/2006 Sb - Public Procurement, specifically §78 - Evaluation Criteria, which states that the main selection criteria for all bids must be either the economic benefits of the proposed bid or the lowest bid cost. The above noted indicates that the LCC may be incorporated into such tendering as part of the economic benefits evaluation [1].

In order to calculate the LCC it is essential to establish a transparent model, which will unambiguously evaluate the proposed bids from the cost-effectiveness point of view. This paper presents the method, which incorporates pre-defined requirements for the calculation of the LCC [2], and offers pre-determined weighting criteria for evaluating the proposed solutions of bridges and estimating the overall value of each bid. The method uses a web-based tool and enables the bidders to clearly estimate the overall LCC for their bid preparation. In turn the tender committee has in its hands the same tool that allows them to verify independently all results. In our view, the main goal of any like tender should not be rewarding the lowest cost bid, which is most likely to generate - long term - the higher operational costs, but to effectively assess and account for all factors affecting the Life Cycle of an asset in order to enhance its overall economic effect [2].

Hence, the application creates indirectly an overall more transparent tendering process and does eliminate the potential of being unable to check errors and flaws of the submitted bids since the application mandates the same both for the bidder and the reviewer. Ultimately, by including the LCC method in tendering, allows the tender committee (likely the operator) to understand the costing long-term components of the designed assets - in this case bridge structures [3].

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2. Tenders evaluation

The basic evaluation criterion for awarding a public contract in accordance with § 78 paragraph 1 of the Law is the economic advantage of a tender. The economic advantage of a tender is evaluated in relation to the following partial evaluation criteria and the importance [4], which represent a share of the sub evaluation criteria in the overall assessment. Partial evaluation criterion and its importance in the overall ranking:

The total tender price without VAT – 60%
Operating costs (long-term costs of restoration and maintenance of the bridge structure calculated with the Bridgepass application created by the Faculty of Civil Engineering in Prague) – 40%

The subject of evaluation of tenders within the sub-criterion "total bid price" means the price excluding VAT, in Czech crowns. The best evaluated bid will be the one containing the lowest proposed price. Within the sub-criterion "operating costs" is the subject of evaluation the level of technical design of the bridge structure from the perspective of long-term costs and the costs of restoration and maintenance of the bridge structure. Costs of restoration and maintenance of the bridge structure are calculated with the Bridgepass application created by the Faculty of Civil Engineering in Prague.

The best evaluated tender is the one containing technically and legally feasible solution of the bridge structure, which is from the perspective of long-term costs of renovation and maintenance of the bridge structure, the most efficient (i.e. economically the most beneficial from the point of view of the contracting entity) compared with other evaluated tenders. The long-term aspect is related to the period arising from the expiry of the warranty period of the bridge structure to the expiration of the service life of the bridge structure in the duration of one hundred (100) years. [5] When determining the long-term costs of renovation and maintenance of the bridge structure the inflation is not taken into consideration. For the evaluation of tenders within the individual partial evaluation criteria, the evaluation committee uses a scoring scale from 0 to 100. Each tender is assigned a point value within each sub-evaluation criterion, which reflects the success of the tender in the context of the partial evaluation criterion.

The total tender price is evaluated as follows. The most profitable tender (the tender that contains the lowest total bid price) within the sub-criterion "total bid price without VAT", is assigned 100 points. The others are assigned a point value according to the formula 1.

$$POINTS = 100 * (\text{The lowest bid price}) \,/\, (\text{evaluated tender}) \tag{1}$$

The operating costs are evaluated on the basis of the output of the application software Bridgepass created by the Faculty of Civil Engineering in Prague. The evaluation commission prepares the ranking of tenders from the most to the least appropriate and assigns 100 points to the best tender. The best evaluated is the tender, that offers, in comparison with others, the most economical technical design of the bridge structure from the perspective of long-term costs and costs of restoration and maintenance of the bridge structure.

$$POINTS = 100 * (\text{tender with the lowest LCC}) \,/\, (\text{evaluated tender}) \tag{2}$$

The point values of tenders within each partial evaluation criterion are multiplied with their corresponding importance according to the table mentioned above and the results are rounded to two decimal places. Followed by the sum of the rounded values, the point value representing total evaluation of the tender is established. On this basis, the evaluation committee determines the order of tenders.

3. Software solution

The Bridgepass application follows the Buildpass application that was primarily aimed on the evaluation of LCC buildings [6]. Buildpass application dealt also partially with the issue of bridges, but the Bridgepass application covers this issue in detail and even in wider spectrum. This application offers easier handling and availability of LCC evaluation tool.

The Bridgepass application processes the estimated costs of maintenance and restoration at the level of individual structural elements. Each design element has a defined course of these costs, considering the technological linkages to other structural elements of the bridge. The result is dependent on the assessment of structural components and materials that are used. The application returns the sum of the discounted costs of restoration and maintenance for a specified period. This value is taken as the basis for evaluation of the criteria.

There will be a web application, with which candidates could free and anonymously calculate the approximate value during the selection process.

Bridgepass application calculates the costs of renewal and maintenance, which are generated by the following structural elements: abutments, pillars, bridge deck (substructure), bearings, insulation of deck, drainage, roadway, cornice, railings, crash barriers, expansion joints and noise barriers. Structural elements can be entered in the predefined type / material variations [7]. If the candidate uses a material that is not contained in the database, this situation is resolved by adding the element into the database. If there is a combination of materials used for one component, these materials are defined as separate structural elements. Variant solutions of structural elements can be seen in Table 1.

Table 1. Variant solutions of structural elements.

Structural element	**Type of structural element**		**Structural element**	**Type of structural element**
The bridge deck (substructure)	monolithic prestressed		Drainage	fiberglass
	monolithic non-prestressed			galvanized
	prefabricated prestressed			plast
	prefabricated non-prestressed			copper
	steel			stainless steel
	composite steel-concrete		Expansion joints	cantilever expansion joint
	composite reinforced concrete			modular expansion joint
	composite Atmofix			nosing expansion joint
Bearings	elastomeric bearings			mat expansion joint
	roller bearings			buried expansion joint
	rocker bearings			Elastic expansion joint
	pot bearings		Noise barriers	concrete
	spherical bearings			brick
Insulation of deck	asphalt strips			plastic
	asphalt screed			softwood
	asphalt coating			hardwood
	epoxy screed			ceramic
	epoxy tar screed			metal
	polyurethane screed			plexi
	polymer coating			

Bridgepass application is available on the website http://www.cesti.cz/bridgepass/. For evaluation, the structural elements are selected according to the type or material that will be used and after that the area (amount) of the element is filled. After completing all items, the application returns the value of the anticipated recovery of costs of defined bridge construction for a period of 100 years of operation by pressing “Calculation” button.

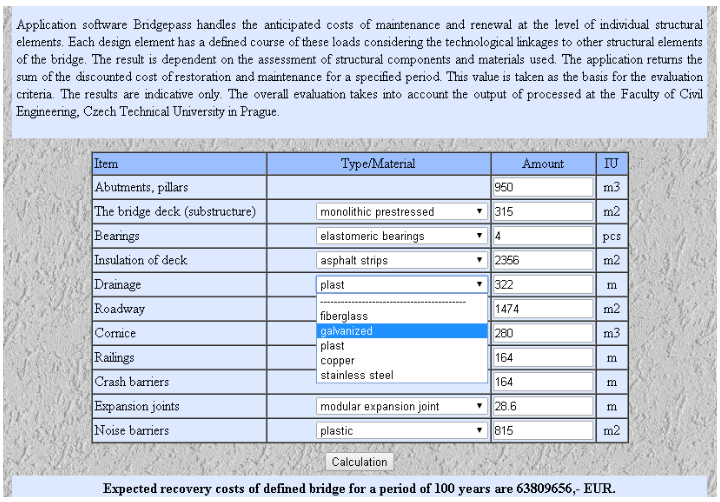

Figure 1. Web interface of the Bridgepass application

4. Conclusions

As an important factor taken into consideration is LCC, which play an important role in building bridges with a lifetime counted for hundred years. The point is not only cheap to build, but also cheap to operate. After that it is necessary to find the best deal that joins these two factors. Successful implementation of LCC cost evaluation using Bridgepass application is an example of what direction can be taken when evaluating public tenders. Of course, the current state cannot be taken as definitive, but there are already suggestions how to improve evaluation methods, mainly about fulfillment of database data of lifespan and prices of individual components. There are companies that have a large database full of information about operation of bridge structures throughout Europe. There is a space for further development and application of methods for assessing LCC bridges.

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A Risk Assessment and Management Methodology for the Improvement of Safety and Protection of Ammunition and Explosive Facilities

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Abstract

Ammunition and Explosive (A&E) facilities are inherently prone to high hazard potential because of internal accidental explosion that can lead to tremendous and irreversible consequences to life and property. This research introduces the development and the implementation of a comprehensive risk analysis model for a typical A&E facility subjected to accidental explosion. The risk analysis model incorporates blast-response models and a Benefit-to-Cost-Ratio (BCR) analysis that assesses the economic benefits of the alternative protective solutions across the expectancy of casualty, the direct and indirect economic losses. The model consists of four phases: (1) scenario analysis – six different scenarios were developed and analyzed as follows: Three TNT charges at the weight of 1, 10, and 50 Kgs were detonated, each at two positions: (I) Spherical charge, at one meter above the floor surface; and (II) Hemispherical charge at the floor level. The blast waves arises from the examined scenario were simulated and analyzed by BLASTX software for two cases: typical A&E building with or without openings. (2) Pressure impulse diagrams analysis – the assessment of personnel harmed at different levels of severity (body and lung damage); (3) Risk Analysis and (4) Benefit-to-Cost-Ratio-Analysis (BCRA) for the examination of the economic feasibility of several alternative protective solutions such as: addition of steel plates to exterior walls and interior partitions, polymer sheets, or reinforced concrete (RC) internal partitions. Based on the literature review, the annual probability of an accidental explosion in A&E facilities was assumed to be 4.7×10^{-3}-4.7×10^{-2}. The BCR ratios of all the suggested alternative protective solution ns were found to be between 1.25 (1 Kg - opened openings A&E building) and 14.75 (50 Kg - opened openings A&E building). The risk analysis reveals that all protective solutions examined are highly effective in terms of expectancy of risk. It is recommended that the Safety regulations of A&E facilities be upgraded in light of the current research.

Keywords: Accidental Explosion; Ammunition and Explosive Facilities; Pressure-Impulse Diagrams; Risk.

1. Introduction

Interior explosion, is the most common extreme event that occurs in ammunition and explosive (A&E) facilities during industrial processes such as: processing, manufacturing, maintenance, renovation, demilitarization and similar operations. The explosion can lead to different kind of failures, from localized failure up to cascading failure in and out the facility thus, it can lead to tremendous and irreversible consequences to life and property. The principal effects of the explosion to be considered are: blast pressure, primary and secondary fragments and thermal hazards [1]. High pressure, for example, can cause irreparable damage as eardrum rupture and lethality due to lung damage. It also might cause building to collapse and turn into debris and rubbles. Primary and secondary fragments might fly with high velocity and shock wave (moving through the structure or the ground) might cause people overturned or fall down with possible injuries or fatalities.[2, 3] therefore, there is a need to design those structures to resist the effects of interior accidental explosions and to accomplish personnel protection. This research introduces the development and the implementation of a comprehensive risk analysis model for a typical A&E facility subjected to accidental internal explosion.

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2. Methodology

The suggested risk analysis model incorporates blast-response models and a Benefit-to-Cost-Ratio-Analysis (BCRA) analysis that investigates the economic benefits of the alternative protective solutions across the expectancy of casualty, the economic loss and the loss of the production activities. The model consists of four phases as presented in Figure 1.

Phase 1: Scenario Analysis for all the following combinations:
3 TNT charges: 1, 10, and 50 Kgs.
2 positions: (I) Spherical charge, at one meter above the floor surface; and (II) Hemispherical charge at the floor level.
2 examine cases: A&E building with and without opening.

Phase 2: Pressure - Impulse (PI) diagrams analysis
-using pressure-impulse lethality (or survivability) curves for the estimation of lung and rupture of the eardrums damage.

Phase 3: Risk Analysis
The risk equation:
R($)= P(IE) · (1-P(E)) · C

:Where
-**R**Expected risk ($)
1-P(E) - Vulnerability of the A&E facilities to a given explosion. [%]
C-Consequence of the event [$].

Phase 4: Benefit to Cost Ratio Analysis
The decision criteria:
BCR>1
Where:
BCR= $\frac{unmitigate\ state - mitigate\ state}{mitigation\ costs}$

Figure 1: Risk Analysis flow chart.

The following paragraphs delineates the four Phases:

Scenario analysis – six different scenarios were developed and analyzed as follows: Three TNT charges at the weight of 1, 10, and 50 Kg were detonated, each at two positions: (I) Spherical charge ,at one meter above the floor surface; and (II) Hemispherical charge on the floor level. The blast waves arises from the examined scenario were calculated by BLASTX software for two discrete cases: typical A&E building with or without openings that because, when an explosion occurs within a structure, the peak pressure associated with the initial shock front will be extremely high and, in turn, will be amplified by reflections within the structure. In addition, the accumulation of gases from the explosion will exert additional pressures and increases the load duration within the structure. The combined effects of both pressures eventually may destroy the structure if it is not strengthened sufficiently or if adequate venting for the gas and shock pressure is not provided, or both. For structures that have one or more strengthened walls, venting for relief of excessive gas or shock pressures, or both, may be provided by means of openings in or frangible construction of the remaining walls or roof, or both. This type of construction will permit the blast wave from an interior explosion to spill over onto the exterior floor surface. These pressures, referred to as exterior or leakage pressures, once released from their confinement, expand radially and act on structures or persons, or both, on the other side of the barrier. Figure 2 represents the reprehensive facility for the scenario analysis. The doors and windows at the exterior walls were considered as opened or closed. The regular steel doors between the rooms are assumed to be opened. The facility floor, walls, and roof are assumed as rigid for the blast simulation based on BLASTX and the exterior wall No. 16 of room 1 was considered to be with or without opening of 456 by 456 cm (half wall area). The simulation results, for each scenario alternative, provide pressure and impulse values at selected points (points 1 to 26 at figure 2). That will be the input for Phase 2.

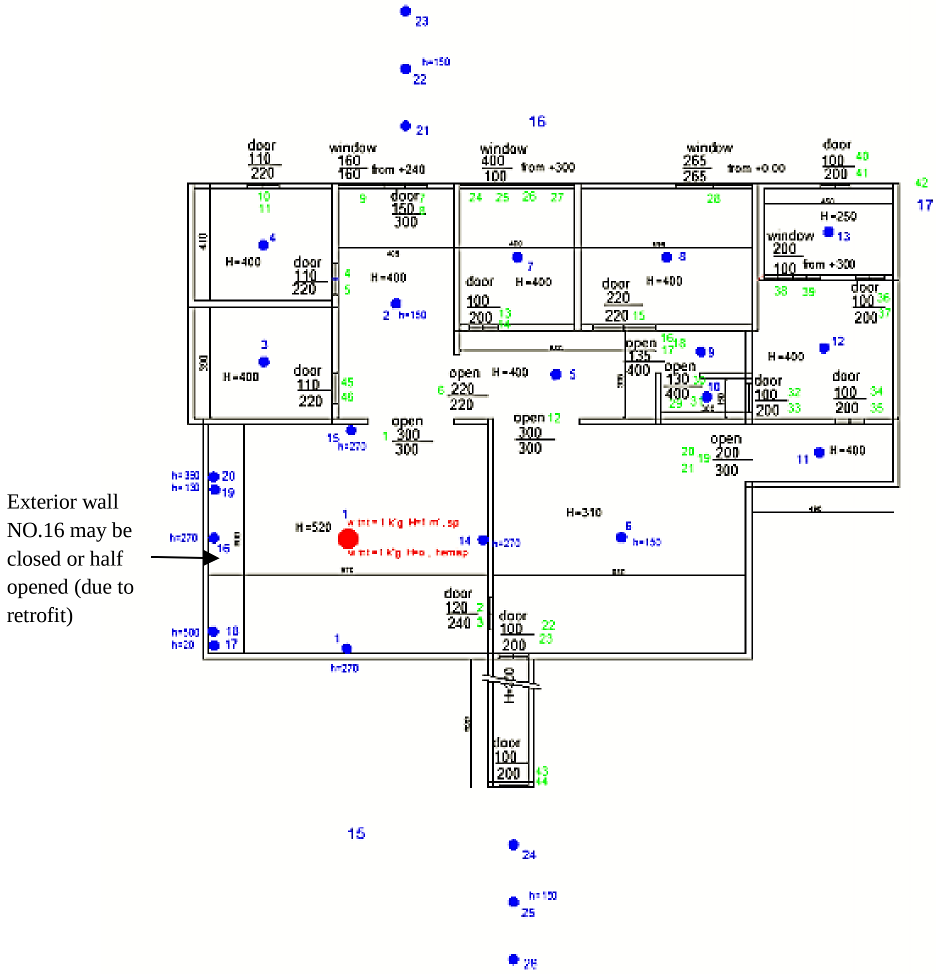

Figure 2-A reprehensive A&E facility and 26 selected study points ( ) for the blast simulations of: 1, 10, and 50kg of TNT Spherical charge, at one meter above the floor surface; and of 1, 10, 50kg Hemispherical charge at the floor level (presented as red point)

Pressure impulse diagrams analysis - The assessment of personnel blast damages was calculated, according to the simulation results at point 1 to 26, by Pressure and Impulse (PI) diagrams (Fig.3). Pressure and impulse diagram is a useful design tool that provides tangible and transparent assessment of the response to a specified load. With a maximum displacement or defined damage level, the diagram indicates the combinations of load and impulse that will cause failure or a specific damage level. To assess the expected mortality and injury rate we used pressure-impulse lethality (or survivability) curves (Fig 3) [4]. Personnel are sensitive to the incident, reflected and dynamic overpressures, the rate of rise to peak overpressure after arrival of the blast wave, and the duration of the blast wave [5-9]. Parts of the body where there are the greatest differences in density of adjacent tissues are the most susceptible to primary blast damage. Thus, the air-containing tissues of the lungs are more susceptible to primary blast than any other vital organ. Other harmful effects that have been considered in this research were the rupture of the eardrums and the damage to the middle ear (Fig.4) [10-13]. Every test point, from each of the six scenarios, was classified to damage level and to the expected costs according to the classification presented in Table 1.

Table 1. Damage category, rate of survival and cost expectancy.

Damage Category	Rate of survival	Cost ($)
Mortality	<0.01	1,000,000
Severe injury	0.01-0.5	1,200,000
Moderate injury	0.51-0.90	100,000
Light injury	0.91-0.99	10,000
No injury	1.00	0

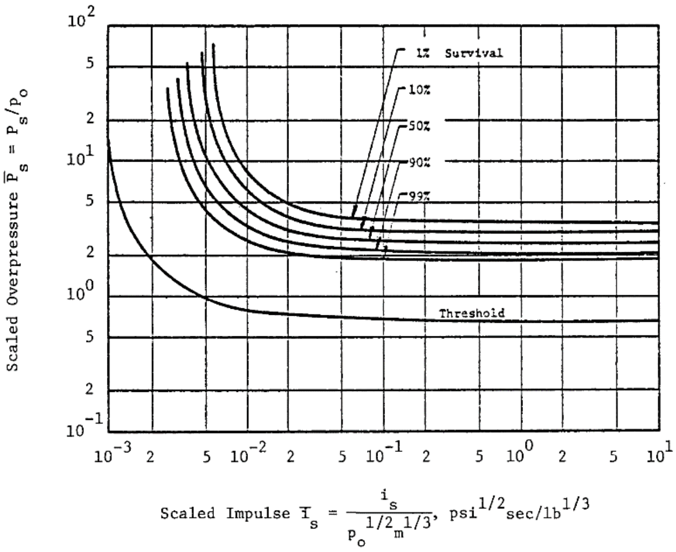

Figure 3-P-I curves for lung damage [4]

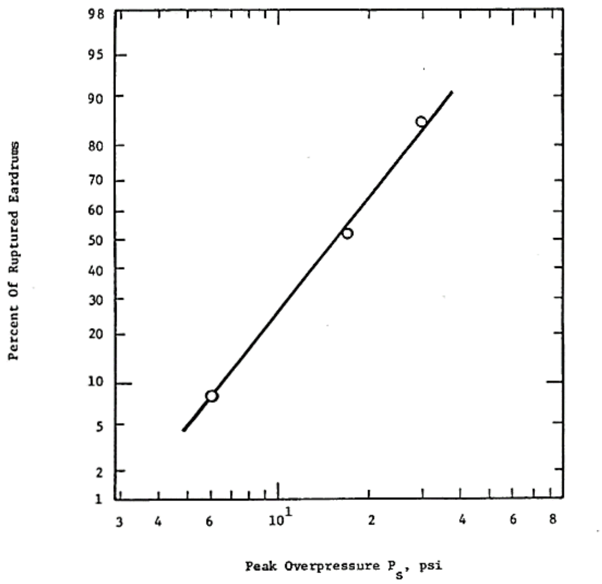

Figure 4-Eardum rapture damage as function of peak overpressure [4]

Risk analysis- the risk expectancy (for every test point, from each of the six scenarios) was calculated using Equation 1 as follows:

$$R = P(IE) \cdot (1-P(E)) \cdot C \qquad (1)$$

Where:
R - Risk expectancy associated with the Interior Explosion event [$];
P (IE) - Probability/Likelihood of the Interior Explosion event
P (E) - Effectiveness of the protective system to prevent the event
(1-P(E)) - Vulnerability of the Ammunition and explosive facilities to a given explosion, derived from the ineffectiveness of the protection system

C - Consequence of the event [$].

The probability of the Interior Explosion event, P(IE), was found to be according to the literature [14-17] around 4.7×10^{-3}. The consequences assessment includes estimation of the expectancy of casualties and injuries [18-21], and the economic loss due to damage to the facility (direct loss) and the loss of the production activities (indirect loss). The protective effectiveness percentage was accomplished by analyzing the expected damage to the structure stability based on [23].

Benefit-to-Cost-Ratio (BCR) -The economic viability of the proposed solutions (with or without opening) was carried out using the Benefit-to-Cost-Ratio-Analysis (BCRA) as follows:

$$\frac{Benefit}{Cost} = \frac{R(Unmitigated\ \ state) - R(mitigated\ \ state)}{Mitigation\_Cost} > 1 \qquad (2)$$

3. Results

The Risk expectancy results for all the six mitigation scenarios are depicted in Table 2. The finding of the analyses reveals that explosions of one kg of TNT caused only minor structural damage, the 10Kg TNT explosion caused moderate structural damage, while the 50 kg. TNT explosion caused severe structural damage. The risk analysis reveals that all protective solutions examined are highly effective in terms of expectancy of casualty. All the protective solutions were found to be economic since BCR ratios ranged between 1.25 (for 1 kg- opened openings) and 14.75 (50 kg– opened openings) as shown in Table 3.

Table 2- Risk expectancy oב the six mitigation alternatives.

Mitigation alternative	Consequences (NIS)	P(IE)	1-P(E)	Risk (NIS)	Cost of Protection (NIS)	Total (NIS)
1 kg, opened windows	12,738,800	0.0047	0.05	29,936	141,000	170,936
1 kg, closed windows	39,734,400	0.0047	0.15	280,155	30,000	310,156
10 kg, opened windows	34,811,120	0.0047	0.3	490,836	141,000	631,837
10 kg, closed windows	46,953,600	0.0047	0.4	882,727	30,000	912,728
50 kg, opened windows	99,047,400	0.0047	0.9	4,190,847	141,000	4,331,847
50 kg, closed windows with additional opening	106,233,920	0.0047	0.9	4,493,694	158,000	4,651,695

Table 3- Benefit to Cost Ratio (B.C.R.) analysis of mitigation alternatives.

Mitigation alternatives	Benefits (NIS)	Costs (NIS)	BCR
1 kg, opened windows	139,220	111,000	1.25
10 kg, opened windows	280,891	111,000	2.53
50 kg, opened windows	1,300,955	111,000	11.72
50 kg, closed windows with additional opening	748,282	128,000	5.84

4. Summary and conclusions

Interior Explosions in A&E facilities might cause massive consequences to life and property. That why there is a need to develop a comprehensive risk analysis model, to assess whether the prevailing risks in A&E facilities exposed to Interior Explosions are acceptable and whether a reduction in the prevailing risk as a result of a risk mitigation strategy worth the additional investment, and, if so, to what extent. Various retrofit and protective solutions such as protective doors can be used in order to improve protection and safety to prevent fatalities, and to strengthen the structure with its dynamic capabilities. The methodology can be applied for any similar facility. The findings of the BCRA indicate that the existing protection standards for A&E facilities should be reviewed and reassessed in light of the high risk expectancy and the economic viability of upgrading and protection alternatives. Additional safety and protection measures such as openings are to be considered and be required in the regulations.

Further research is recommended to investigate the effectiveness and economic efficiency of protective alternatives such as sheets (such as P.V.C.), steel partitions, and other advanced protective solutions.

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Performance of LEED Energy Credit Requirements in European Countries

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Abstract

Construction industry influences the environment a great deal by using different resources. Efficient use of resources is important for sustainability considerations. Heavy consumption of energy is one of the reasons causing adverse impacts on the built environment. The interest in sustainable construction is growing worldwide. Green building systems are used to certify the projects as green buildings in different countries. All these systems have similar approaches to build sustainably and they all highlight requirements related to energy consumption with a significant emphasis. One of the most recognized green building certification systems, LEED addresses energy optimization, green power and on-site renewable energy in much detail. The maximum credit points can be achieved from “energy and atmosphere” category in LEED. However, the use of LEED in countries other than the U.S. can be difficult as local conditions and practices are influential in earning credentials. This study aims to review the practices of “energy and atmosphere” category of LEED v3 2009 New Construction in European countries. Analysis of practices in selected countries is made based on credit performances, which can display variations depending on local conditions. It is expected that practitioners in these countries will benefit from the credit patterns, providing improved insights about on-site real applications.

Keywords: LEED; energy and atmosphere; Europe; sustainable construction; credit.

1. Introduction

The buildings are responsible from the consumption of energy throughout their life cycles and reported as consuming 30-40% of all primary energy worldwide [1]. Energy is used in the production and transportation of construction materials, during buildings’ operations, and dismantling and demolition in the construction sector [2]. Negative environmental impacts arise from several construction activities, manufacturing of building materials and transportation. All of these are consuming energy, generating emissions linked to global warming, acid rain and smog [3].

Sustainable construction principles refer to minimizing all these negative impacts. The interest in sustainable construction is growing particularly gaining a momentum over the past two decades. Green building certification systems are being frequently used as a means of rating buildings as sustainable. There are several systems developed in different countries. Some countries use their own systems, while some others prefer to adopt them. LEED certification system was first pilot tested in 1998 by United States Green Building Council (USGBC) in the U.S. The system aims to use resources efficiently by using less energy and water, reducing greenhouse gas emissions, and focusing on materials to reduce the effects of their harmful components. According to USGBC project database, 87,216 projects are listed as either registered or certified through LEED as of March 14, 2016.

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LEED is one of the certification systems, which is also widely used in different countries, other than the U.S. There are five rating systems listed in LEED; Building Design and Construction (BD+C), Interior Design and Construction (ID+C), Building Operations and Management (O+M), Neighborhood Development (ND), and Homes. BD+C applies to buildings that are newly constructed or going through a major renovation, including New Construction (NC), Core & Shell, Schools, Retail, Hospitality, Data Centers, Warehouses & Distribution Houses, and Healthcare. Although LEED v4 has been launched in 2013, LEED v3 2009 is still in effect until October 2016. Buildings certified through latest version is rather few when compared with buildings certified using LEED v3 2009.

Sustainable construction practices are frequently addressed and implemented in the the EU. This study aims to review the practices of “energy and atmosphere” category of LEED in European countries for New Construction with LEED v3 2009. Analysis of practices in selected countries is made based on credit performances, which can display variations depending on local conditions. It is expected that practitioners in these countries will benefit from the credit patterns, providing improved insights about on-site real applications.

2. LEED Certification System – New Construction (NC)

LEED Building Design and Construction (BD+C) can be used for eight different types of projects depending on projects’ needs, including New Construction (LEED-v3 2009 NC). The system addresses design and construction activities for both new buildings and major renovations of existing buildings. This includes major HVAC improvements, significant building envelope modifications and major interior rehabilitation.

Energy and atmosphere credit category has the largest portion of the maximum achievable points in LEED v3 2009 and accounts for approximately 32% for New Construction rating system of the total points. The credits and corresponding points are given in Table 1. A building can achieve four certification levels, certified (40-49 points), silver (50-59 points), gold (60-79 points), and platinum (80 and up).

The category approaches energy from a holistic perspective, addressing energy use reduction, energy-efficient design strategies, and renewable energy sources. Being worldwide mix of energy resources, oil, coal and natural gas are non-renewable resources [4]. The efficient usage of existing limited resources and construction of environmental-friendly buildings have gained importance [5].

There are several strategies addressed in sustainable buildings to support energy efficiency. Cost-effective systems, tools, means and measures are encouraged. Building orientation, glazing selection, choice of climate-appropriate materials are some examples for design strategies. Employing passive heating and cooling, natural ventilation, and high-efficiency HVAC systems partnered with smart controls further reduce a building’s energy use. The generation of renewable energy on the project site or the purchase of green power allows portions of the remaining energy consumption to be met with non–fossil fuel energy, lowering the demand for traditional sources [4]. Commissioning is regarded as a critical process to ensuring high-performing buildings. Early involvement of a commissioning authority helps prevent long-term maintenance issues and wasted energy by verifying that the design meets the owner’s project requirements and functions as intended.

Table 1. Credits in LEED v3 2009 New Construction rating system

LEED v3 2009 New Construction	Pts.
Pre1. Fundamental Commissioning of Buildings Energy Systems	-
Pre2. Minimum Energy Performance	-
Pre3. Fundamental Refrigerant Management	-
EAc1. Optimize Energy Performance	1-19
The minimum energy cost savings percentage	
12%	1
14%	2
16%	3
18%	4
20%	5
22%	6
24%	7
26%	8
28%	9
30%	10
32%	11
34%	12
36%	13
38%	14
40%	15
42%	16
44%	17
46%	18
48%	19
EAc2. On-site Renewable Energy	
Percentage renewable energy	
1%	1
3%	2
5%	3
7%	4
9%	5
11%	6
13%	7
EAc3. Enhanced Commissioning	2
EAc4. Enhanced Refrigerant Management	2
EAc5. Measurement and Verification	3
EAc6. Green Power	2
Max. Total	**35**

3. Energy and Atmosphere Credit Achievements in Selected Countries

The adverse impacts of excessive energy consumption forced by many countries make efforts to reduce energy consumption and CO_2 emission [6]. According to Directive 2010/31/EU of the European Parliament and Council, buildings consume 40% of energy in the European Union. It is required to reduce energy consumption and the use of energy from renewable sources [6]. Therefore, a binding legislation named “climate and energy package” is proposed by the European Commission, which was agreed by the European Parliament and Council in 2008 and became law in 2009. This package set an integrated approach to climate and energy policy known as 20-20-20 targets. These are reduction in EU greenhouse gas emissions of at least 20% below 1990 levels, using renewable resources for 20% of EU energy consumption, and 20% reduction in primary energy use with energy efficiency improvement technology by 2020 [6,7,8]. The European Commission also revised the analysis of options to move beyond 20% in 2012 [9].

LEED is originally developed for U.S. construction sector and takes into account local conditions and practices applicable in the U.S. Recognized as a widely used certification system in the world, it has been used in other countries since its introduction. Since the local conditions, practices, material types, climate conditions, market demands and expert experiences can vary significantly based on locations, achievement in the credits can differ according to the countries. Analyzed LEED v3 2009 New Construction certified buildings in Europe in this study are listed in Table 2. The number of buildings, attained certification levels, and country names can also be seen. The scorecards of these buildings were downloaded from USGBC project web site. The list consists of 20 countries. Figure 1 shows proportion of achievements in Energy and Atmosphere credits of them. Table 3 illustrates the results obtained from Kruskal-Wallis test, which examines the buildings' mean ranks.

Table 2. Breakdown of analyzed buildings – New Construction

	Certification Level			
Countries	**Platinum**	**Gold**	**Silver**	**Certified**
Austria	3	5	0	0
Belgium	0	2	1	0
Bulgaria	0	1	1	0
Czech Republic	2	1	1	1
Denmark	2	2	0	0
Finland	3	10	3	1
France	5	2	3	0
Germany	5	28	10	0
Greece	0	1	2	0
Hungary	0	2	1	0
Ireland	1	2	1	0
Italy	2	1	1	0
Netherlands	1	0	0	0
Poland	0	8	2	2
Portugal	1	3	1	0
Slovakia	0	1	0	0
Spain	8	14	8	4
Sweden	3	18	2	1
Switzerland	1	2	0	0
United Kingdom	0	1	0	1
	37	**104**	**37**	**10**

Figure 1. Credit achievements of LEED-NC 2009 New Construction certified buildings (189 buildings)

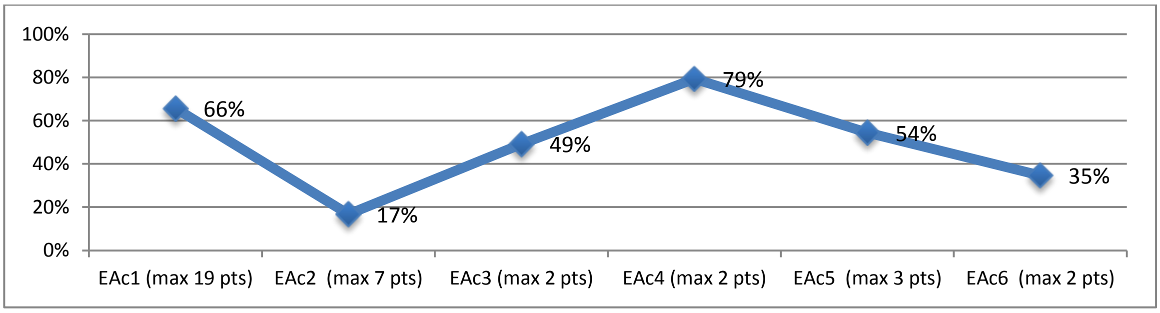

Table 3. Kruskal-Wallis test results of LEED-NC 2009 New Construction certified buildings (189 buildings)

	Certification Level	N	Mean Rank
EAc1	Platinum	37	147.23
	Gold	104	91.83
	Silver	38	66.55
	Certified	10	42.85
EAc2	Platinum	37	137.2
	Gold	104	83.19
	Silver	38	87.93
	Certified	10	88.55
Eac3	Platinum	37	112.35
	Gold	104	95.75
	Silver	38	85.8
	Certified	10	57.95
Eac4	Platinum	37	106.84
	Gold	104	96.33
	Silver	38	82.17
	Certified	10	86.15
EAc5	Platinum	37	115.42
	Gold	104	96.79
	Silver	38	83.07
	Certified	10	46.15
Eac6	Platinum	37	122.73
	Gold	104	91.23
	Silver	38	84.5
	Certified	10	71.5

Table 4. Credit achievements of LEED-NC 2009 New Construction certified buildings

			Maximum Achievable Points						Achievement (%)					
			19	7	2	2	3	2						
Certification Level	**No. of buildings**		**EAc1**	**EAc2**	**EAc3**	**EAc4**	**EAc5**	**EAc6**	**EAc1**	**EAc2**	**EAc3**	**EAc4**	**EAc5**	**EAc6**
Platinum	37	Average	17.7	3.9	1.4	1.8	2.2	1.3	93%	56%	68%	92%	74%	64%
		St.dev.	2.8	3.2	0.9	0.6	1.3	1.0	15%	46%	47%	28%	42%	48%
Gold	37	Average	12.2	0.5	1.0	1.6	1.7	0.6	64%	7%	50%	81%	56%	30%
		St.dev.	5.3	1.5	1.0	0.8	1.4	0.9	28%	22%	50%	39%	48%	46%
Silver	105	Average	9.5	0.6	0.8	1.3	1.3	0.5	50%	8%	38%	65%	43%	24%
		St.dev.	5.7	1.7	1.0	1.0	1.3	0.9	30%	25%	49%	48%	44%	43%
Certified	10	Average	6.9	0.5	0.2	1.4	0.3	0.2	36%	7%	10%	70%	10%	10%
		St.dev.	3.9	1.1	0.6	1.0	0.9	0.6	21%	15%	32%	48%	32%	32%

4. Findings and Conclusions

Energy efficiency is important in green buildings and rated by means of several credits in the certification systems. LEED is originally developed for the U.S. construction practices, however its use is common in other areas of the world. Energy and Atmosphere credit category has the largest share of achievable points in LEED-NC 2009 system promoting sustainable practices in the buildings. This study examines achieved points of a group of buildings certified through LEED-NC 2009 for New Construction system for Energy and Atmosphere credits in 20 European countries. The building inventory consists of 189 buildings. Earned credit points are obtained from USGBC's project directory web site. According to the analysis results, following findings can be highlighted:

The proportions of the maximum achievable points in the Energy and Atmosphere credits earned by the LEED v3 2009 certified buildings considered in the study are ranked as "EAc4 - Enhanced refrigerant management" (79%), "EAc1 - Optimize energy performance" (66%), "EAc5 - Measurement and verification" (54%), EAc3 - Enhanced commissioning" (49%), "EAc6 - Green power" (35%), and "EAc2 - On-site renewable energy" (17%) (Figure 1). EAc4 - Enhanced refrigerant management have been employed frequently as a sustainable strategy. This credit aims to reduce stratospheric ozone depletion. It encourages use of new HVAC equipment that usues on CFC-based refrigetants for new buildings and reuse of existing HVAC systems providing a replacement phase-out schedule for them. The achieved percentages of this credit were determined as 92%, 81%, 65%, and 70% for platinum, gold, silver and certified levels, respectively (Table 4). Mean ranks based on certification levels are provided in Table 3.

EAc1- Optimizing energy efficiency aims cost savings percentage for each point threshold specified in the system. Highly efficient HVAC and lighting systems can be adopted to provide cost savings by redcing comsumption of energy in the buildings. This credit ranked as the second credit. The achieved percentages were identified as 93%, 64%, 50%, and 36 % for platinum, gold, silver, and certified buildings, respectively (Table 4). Platinum buildings achieved significantly higher mean scores (Table 3).

EAc5- Measurement and verification further encourages the prerequisite for the accountability of energy consumption over time. Achivements were recorded as 74%, 56%, 43%, and 10% for platinum, gold, silver, and certified buildings, respectively (Table 4). It was majorly pursued by platinum buildings (Table 3).

EAc3 – Enhanced commissioning credit suggests early involvement of commissioning process and additional activities after systems performance verification is completed. 68%, 50%, 38%, and 10% achievements were determined for platinum, gold, silver, and certified buildings, respectively (Table 4). Additional costs and the lack of experience can affect the use of commissioning services.

EAc6 – Green power encourages the development and use of grid-source, renewable energy technologies on a net zero pollution basis. The low achievement percentage of 35% (Figure 1) indicates that project owners preferred to earn points from other credits. Certification-level based percentages were obtained as 64%, 30%, 24%, and 10% for platinum, gold, silver, and certified buildings, respectively (Table 4).

Use of EAc2- On-site renewable energy options were the least addressed solutions, probably because they are costly and not easy to find. This credit encourages using solar, wind, geothermal, low-impact hydro, biomass and bio-gas strategies to reduce environmental and economic impacts. Platinum, gold, silver, and certified projects scored 56%, 7%, 8%, and 7%, respectively, indicating that only platinum buildings pursued majorly after this credit (Table 4). Table 3 shows the significant difference between platinum and other levels.

The objective of this study was to examine the LEED v3 2009 New Construction practices in the Energy and Atmospehere credits for selected European countries. Achievement percentages points out practitioners' efforts to earn points in this category. Future studies may involve assessment of other credit categories to provide better understanding of employing sustainable solutions required for green building certification systems.

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Optimization of Construction Site Safety Supervision Activities

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Abstract

A proposed safety management methodology for large and complex construction sites is presented. The methodology includes a risk control process based on continuous improvement, which utilizes data collected in an audit program to evaluate the safety performance of different crews on site. The methodology utilizes information on ratios that can be determined between different types of safety events in order to identify deviations that require control actions, and in order to reduce the number of severe safety events by reducing the number of unsafe acts that lead to such events.

Keywords: Construction safety; Optimization; Site supervision; Statistical analysis

1. Introduction

Many safety management methods that are applied on construction sites are in essence retroactive. Such methods include, for example, disciplinary actions against employees violating safety requirements, safety-event investigations, performing coaching and teaching after the occurrence of an unwanted event, etc. It appears that the larger and more complex the construction site is, the larger is the gap between the need to reach an adequate safety level on the site and the actual ability to achieve and maintain this. As sites increase in size and complexity, additional management tools are required to ensure safety.

An alternative approach is that of pro-active safety management. In this approach technological tools and methodological approaches are used in order to raise safety levels, by initiating activities to prevent safety events rather than merely reacting to them. Examples for implementing this approach are:

Performing safety audits throughout the site and identifying trends. Once the problematic sites and locations are identified, additional supervision and coaching will be executed at those specific locations.

Using safety indicators to evaluate performances.

Data mining of the results of safety audits.

Using automated optimization to determine the most efficient supervision method for increasing compliance.

Supervision and on-the-spot coaching is a good tool for enforcing compliance and reducing safety risk levels. In this research, a methodology for maximizing safety supervision abilities is being developed. By ranking specific features of an activity (based on observation, statistics, expert knowledge, etc.) an objective evaluation of the activity's risk-level can be performed. Using the methodology, one can decide which activities require additional supervision, and which activities should be supervised first to achieve the most efficient results. An application of this method may maximize the influence of the on-field staff by helping them to reduce the risk level of dangerous activities, reducing the amount and severity of safety events, and helping to achieve improved safety performances.

1.1. *Traditional methods for maintaining a safe construction site*

A significant number of studies have been carried out to develop tools and models for the planning of safe construction sites. Rozenfeld et al. [1] developed a Construction Job Safety Analysis tool, which focused on the identification of potential loss of-control events for a detailed planning of construction activities, based on data

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collected through interviews. Mitropoulos et al. [2] presented a model of the factors affecting the likelihood of accidents during a construction activity. The model focuses on the characteristics of a project that generate hazardous situations and shape actual work behaviors, and analyzes the conditions that trigger the release of the hazards. Saurin et al. [3] defined a Safety Planning and Control Model that includes three hierarchical levels, for long-, medium-, and short-term safety planning. Proactive and reactive performance indicators were defined for safety control and evaluation, based on the percentage of safe work packages and actual accident data. Jannadi and Almishari [4] developed a risk assessor model [5].

One of the most common methods to manage safety programs is the risk management process. In this method the generated risk level is controlled and reduced to an acceptable level. It is a 3-step process:

- Identification of the risk generated by the activities, the site conditions, etc.
- Evaluation of the identified risks, where the main factors are the probability that the accident will occur if the activity is performed in a particular manner, and the level of severity of the results in case of an occurrence.
- Risk control: in this step it is required to come up with risk reductions and control means to reduce the probability, the severity, or both. Examples of such means can be adding Personal Protective Equipment (PPE) for specific activities, usage of fall protection equipment, using tool secure devices, etc, [6].

A common approach to accident prevention is based on OSHA's violations approach and focuses on prescribing and enforcing "defenses;" that is, physical and procedural barriers that reduce the workers' exposure to hazards [2], other means to raise safety level are having of a training program generated and modified to the site needs and features. The training program can also be modified according to the employee's scope and planned activities, other methods that were found efficient are - Tool Box meetings to raise awareness and communicate information to the employees, PTP, having a designated safety officer on site, safety orientation, and performing drugs and alcohol tests [7].

1.2. *Managing safety in large scale construction sites*

The safety management tools mentioned above can enable a sufficient level of safety on small-scale construction sites. That's been said, it is known that the construction is one of the most dangerous industries world-wide [3], therefor when discussing big sites which contain many crews from a variety of disciplines, belonging to different companies and contractors and with differing standards and commitments towards safety, it is a significant challenge to define a unified safety standard and to enforce and verify that all the safety requirements are being fulfilled. In these cases, additional safety management tools are required.

A commonly used tool for this purpose is to carry out a safety observation program. The purpose of the audits is to examine whether all safety requirements are being implemented on site. Employees and contractors that display good performances receive positive feedbacks and are awarded, while contractors that are observed to violate safety requirements are exposed to punishments and to disciplinary actions.

In order to prevent the reoccurrence of unwanted safety events, good communication and calibration need to be kept. Therefore, after the occurrence of a safety event, the relevant contractor is required to publish a lessons-learned paper specifying the conditions and sequence of events that led to the safety event occurrence. This way, other contractors that are performing similar activities and exposed to similar risks can learn and prevent the next event and increase the general safety level of the whole site.

It may appear as if the requirements that will lead to a safe construction site are quite clear. Yet, two factors jointly make it difficult to obtain this goal. The first factor is that that there are limited safety supervision resources (safety personnel). Therefore, their ability to influence and prevent safety violations is limited. The second factor is that construction sites are dynamic, ever changing, have multiple high risk activities that are executed in parallel and have changing environmental conditions. The combination of these two factors leads to the understanding that the risk control process has to be continuous and dynamic, so that the activities with the highest risk at a given time will be controlled and monitored.

2. Proposed methodology

On complex construction sites, where sub-contractors with different safety standards are hired, a lack of clarity often exists regarding the safety expectations and requirements. This research seeks to develop a safety management methodology in order to minimize this lack of clarity and in order to verify that all the crews on site are in compliance with the safety requirements.

The proposed methodology includes a risk control process based on continuous improvement, combined with the maintenance of an audit program that will help to better evaluate the safety performances and will enable the evaluation at any time of locations that require additional supervision, coaching and support. This approach is based on a Plan Act Do Check (PADC) methodology (Figure 1).

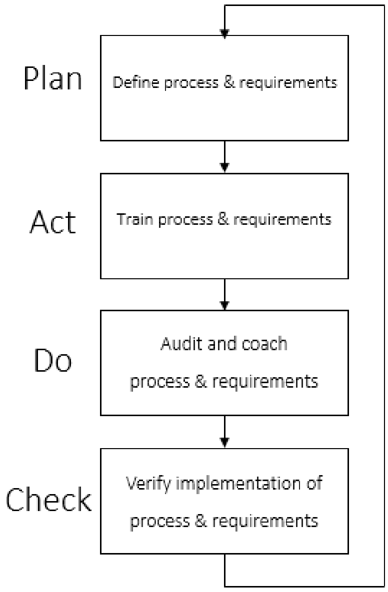

Figure 1: PADC methodology for continuous safety management process

In this methodology, the risk management process is carried out in parallel with the approval of activities. Supervision resources are allocated in accordance with the risk control plan to ensure maximum impact. While activities are being executed, safety audits are conducted to analyze and evaluate safety and compliance performances. According to the results of these audits, the means of improvement (e.g. training, on-site coaching, disciplinary actions, etc.) are planned and implemented.

The methodology helps to define the construction site's safety level by using time-dependent variables to describe the crews, and quantifies and ranks features that may predict their risk exposure and the probability of the occurrence of a safety event. These variables include the crew's learning curve, its experience, safety training, management commitment, etc. The planning and implementation of the methodology is oriented towards constant improvement and maximum benefit from the actions of the safety staff. The methodology includes assigning the staff to the appropriate locations, a constant reevaluation of safety needs, and continuous risk evaluation.

2.1. *Implementation of the methodology*

The first phase of the methodology is to define the safety requirements and expectations while executing an activity. These requirements may come from standards, regulations, the company's requirements, past experience of similar operations, etc.

The second phase includes training prior to the actual execution of the activity. The duration, method of training, and other requirements will be determined according to the complexity of the activity and the level of risk.

The third phase takes place while the activity is being executed on site. Safety audit teams evaluate the performances of crews, and check if the safety requirements are being implemented. In general, good performances will be rewarded and encouraged, while poor performances will lead to on-site training (or stopping the work in case of major violations). Another purpose of this phase is to determine if the activity is planned in a controlled manner and if additional safety means are required. The audit data will be stored and the managers of the crews will be informed of the safety outcomes.

The fourth and final phase of the methodology includes managerial safety audits. The purpose of these audits is to ensure the implementation of additional requirements (if there are any) and to evaluate the need for changes in the plans.

2.2. *The safety pyramid model*

In his book “Accident Prevention: A Scientific Approach”, Heinrich [8] established a "safety pyramid" model to describe the ratio between different types of safety events in the manufacturing industry. According to this study, safety events occur in the industry at a ratio of 1 major injury or death for every 29 minor injuries, and for every 300 "near misses". Later studies divided the pyramid into 5 layers:

- Unsafe act or condition
- Near miss
- First aid
- Recordable injury
- Fatality.

In additional to determining the different layers of the pyramid, these studies indicated that there is a constant ratio between the layers. According to Bird [9], the ratio between the pyramid layers is 1-10-30-600, which means that for every one fatality or severe injury event, there are 10 first aid events, 30 events of impact or damage to equipment, and 600 near misses. The safety pyramid model was developed for the manufacturing industry, which has different features than the construction industry. Therefore, statistical data on the safety events in a large-scale construction site were analyzed in this research in order to see if there are any differences with the existing model, and what are their sources.

Dividing the safety events using a pyramid model emphasizes the idea that a severe safety event is not an act of god. Prior to this event many smaller events will have occurred, and if the organization would have understood their statistical significance it might have prevented the event from happening. Statistically analyzing the data could thus help to identify when the data starts to reflect poor safety performances. The implementation of the proposed methodology will be based on establishing an acceptable level of safety performance for each level of the safety pyramid, and on the constant review of the observed performances on site. Whenever the occurrence of any type of safety event will exceed the acceptable value, a corrective action plan will need to be executed in order to improve the performances and to prevent the occurrence of a higher-level safety event.

In many cases the safety level of a site or type of activity is evaluated by the question if there were fatalities and injuries [6], and their rate. However, a fatal event is just the tip of the iceberg, and it is usually preceded by a large number of unsafe acts and conditions and many low severity safety events. Therefore, it is suggested that safety levels should be evaluated by examining all safety layers, and not just the upper one. In order to do so, it is required to determine the acceptable relative number of events in each layer. Once the safety performances deviate from this number, action is required to improve the performances. Furthermore, since previous studies indicate that there is a constant ratio between the different safety layers, it can be hypothesized that a reduction of the number of events in the lowest layer (unsafe act or condition) will proportionally decrease all the layers above it, and that fewer safety events will occur, both in terms of quantity and severity.

2.3. *Preliminary findings*

Based on the safety audits that were performed in a large-scale construction site, initial findings indicate that in terms of the ratios of events, the construction industry appears to differ from the manufacturing industry. In this case study, approximately 2600 safety audits were made. In the majority of audits the results were “no safety violations”. The outcomes of the remaining audits and the project safety log were analyzed and are summarized in Table 1 and Figure 2.

Table 1. Results obtained in the case study.

Safety event type	#	Factor of proportionality	Percentile
Unsafe act / Condition	950	-	87.2
Near miss	84	11.3	7.7
First Aid	47	1.8	4.3
Injury	8	5.9	0.7
Severe injury / Death	1	8.0	0.1

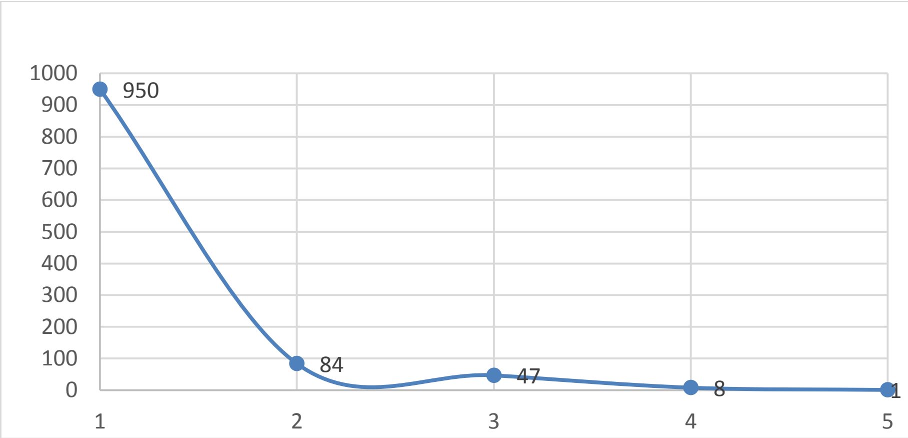

Figure 2: The number of safety events in the case study

These results reflect the safety performances of the sub-contractors from all the different disciplines of construction, such as civil, electric, piping, mechanical, architectural, etc. It can be observed from the factors of proportionality that were calculated that the biggest difference from the conventional models is between the first aid events and the near miss events. While the traditional model predicts a ratio of 1:10, the ratio in this project was 1:1.8. In other words, many more first aid events occurred than would be predicted based on the traditional model

Based on the findings in the case study, specific statistical values can be defined for each type of safety event, which represent the acceptable relative level of occurrence for these events. These values are represented by the calculated percentiles in Table 1 and Figure 3. Continuous monitoring of the site will identify the actual number of events in each category. Any deviation that is observed on the construction site will require the implementation of safety measures.

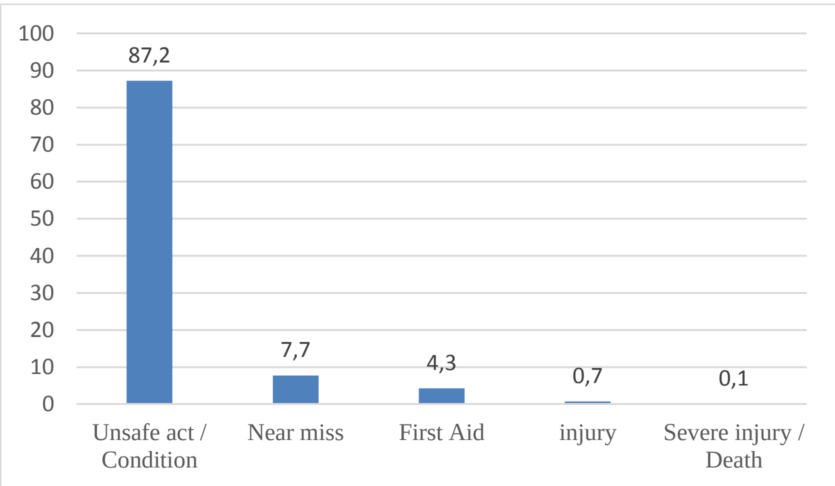

Figure 3: Acceptable relative level of occurrence of safety events

3. Conclusions and further research

A proposed safety management methodology has been presented for large and complex construction sites. The methodology includes a risk control process based on continuous improvement, which utilizes data collected in an audit program to evaluate the safety performance of different crews on site. The methodology utilizes information on ratios that can be determined between different types of safety events in order to identify deviations that require control actions, and in order to reduce the number of severe safety events by reducing the number of unsafe acts that lead to such events.

Initial findings of safety audits that were performed in a large-scale construction site indicate that the construction industry appears to differ from the manufacturing industry in terms of the ratios of safety events. However, additional research is being carried out in order to verify these results.

Further research is being carried out to develop the proposed methodology. This research includes the development of a process to calculate the risk posed by specific activities, based on data that is collected in real-time. In addition, a process is being developed for the definition of safe work areas and the required distances between crews at any time during the project, in order to reduce the impact of safety events.

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The Use of Reclaimed Rain Water in U.S. Cities and USACE Installations

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Abstract

Currently many locations in the United States and throughout the world are facing significant water shortages resulting from climate change, drought, reduced surface aquifer levels, and competing regional requirements for agriculture, municipal consumption, energy production, and environmental requirements. For the U.S. military and the U.S. Army Corp of Engineer (USACE) installations, potential mission shifting or increased growth may be strongly impacted by water restrictions or water unavailability. In many ways, water sustainment at military installations is both a security and sustainability issue. Rainwater harvesting is specifically called out as an approach to meet Army requirements for Low Impact Development as related to storm water. On February 19, 2015, President Obama issued Executive Order 13514 on *Federal Leadership in Environmental, Energy, and Economic Performance*, which sets sustainability goals for Federal agencies and focuses on making improvements in their environmental, energy and economic performance. This paper describes several rainwater collection systems used in various communities. In addition, brief case studies are presented describing rainwater harvesting use at several USACE installations.

Keywords: rainwater harvesting, reclaimed rainwater, USACE.

1. Introduction

Currently many locations in the United States and throughout the world are facing significant water shortages resulting from climate change, drought, reduced surface streams and aquifer levels, and competing regional requirements for agriculture, municipal consumption, energy production, and environmental requirements. For the military, potential mission shifting or increased growth may be strongly impacted by water restrictions or water unavailability [1]. In many ways, water sustainments at military installations are both a security and sustainability issue. Many Department of Defense (DoD) installations are located in water stressed locations. Rainwater capture and harvesting is also currently in uses in various cities and municipalities in the United States and has proven to be an excellent means of increasing water supply. Harvested rain water is also very useful for areas that rely on groundwater with high solids content or with natural contaminants like arsenic or fluoride. It also provides a lower energy cost than other water sources. The idea of harvesting rain water is not a new concept. History teaches us that ancient civilization like Negev desert in Israel, the Mediterranean, India, Greece, Italy, Egypt, Turkey, and Mexico used reclaimed water by building structures to facilitate the process.

1.1. *Rainwater Capture and Harvesting and the benefits*

The use of harvesting rainwater in areas with water stress in which substantial water is lost due to storm runoff, evaporation, or subsurface leaching. The main challenge in harvesting rainwater is the treatment of the water, which includes high solids or contains natural contaminants arsenic and fluoride are common issues or surface water that is prone to degradation from eutrophication, resulting algal issues like taste, odor or toxic compound which can be challenging to treat. Rainwater can be harvested for various uses which include potable water uses, including drinking water, food preparation, showering and washing. These applications would likely require treatment to insure that the water meets state and federal requirements for potable uses. Some beneficial non-potable uses for rainwater are toilet and urinal flushing and vehicle washing. Harvested rainwater use has been proven safe for the following types of applications throughout the U.S. and is approved for use by the Texas Commission on Environmental Qualities (TCEQ) [2].

School Playgrounds and Sport Fields

Landscape Nurseries

Sports Complexes

Golf Courses

Street Median Landscaping

Construction Projects

Street Sweeping

Fire Protection

Residential Landscape

Apartment Landscape

Industrial Cooling Towers

Industrial Processes

In the city of El Paso reclaimed water is being used to maintain golf courses, city parks, school grounds, apartment landscapes, construction, and industrial sites with over 5.83 million gallons per day of reclaimed water.

2. Meeting Communities Needs by Using Rainwater Harvesting

Rainwater can provide 100% of water needs for communities that rely strictly on this resource. The needs on military installations however are greater than what is supplied by rain water. Reasonable goals for rooftop collection for a custom building might be reduce domestic water supply by 40 to 50% for a building that would then the building to meet LEED goals for sewage reduction. Military installations are in most instances small cities estimate that maximized rooftop collection approach could supply about 32% needs. However, they also estimated a 10% goal would be reasonable from an economic standpoint, yielding a 3.2% displacement [3].

2.1. *Rain Water Concerns*

Rainwater harvesting can be used in a wide range of climates. In hot, arid climates, the focus is on efficient collection from big, infrequent weather events. In order to salvage rain water from these events large, underground storage tanks provide water between storms and reduce water losses from evaporation. A concern in wetter environments is the possibility of contaminates, so a system like first flush or rain diverters may be required. These systems flush off the first water from a storm before it enters the storage tank. These systems dispose of water that is mostly contaminated by particulates, bird droppings, and other materials on the roof. Eliminating these contaminants before they enter into your storage and conveyance system is critical to keeping rainwater clean [4]. Another concern are for environments that experience cold temperatures and frequent freezing conditions is that the weather may cause underground rainwater storage tank to freeze.

2.2. *Army Requirements*

Rainwater harvesting is specifically called out as an approach to meet Army requirements for Low Impact Development as related to storm water [5]. On February 19, 2015, President Obama issued Executive Order 13514 on "Federal Leadership in Environmental, Energy, and Economic Performance", which sets sustainability goals for Federal agencies and focuses on making improvements in their environmental, energy and economic performance. Other regulations that govern the use of Rain Water are the Army memorandum on Sustainable Design and Development Policy Update (10/27/2010), OSD EISA 438. Maintaining or reducing predevelopment runoff and the Army's Net Zero Water and Energy. AR 200-1 also states that all Army organizations and activities will comply with applicable Federal, state, and local environmental laws, regulations, and Eos. Therefore, it is essential that the local Army counsel be consulted on the applicability of all laws, regulations, and initiatives in the specific state where the facility resides, and of course all Eos [6].

2.3. *Green Building Council LEED BD+C: Water Efficiency (WE)*

In the U.S., buildings account for 13.6% of potable water use, the third-largest category, behind thermoelectric power and irrigation. Designers and builders can construct green buildings that use significantly less water than conventional construction by incorporating native landscapes that eliminate the need for irrigation, installing water-efficient fixtures, and reusing wastewater for non-potable water needs. The Green Building Market Impact Report 2009 found that LEED projects were responsible for saving an aggregate 1.2 trillion gallons (4.54 trillion liters) of water. LEED's WE credits encourage project teams to take advantage of every opportunity to significantly reduce total water use. The WE category comprises three major components: indoor water (used by fixtures, appliances, and processes, such as cooling), irrigation water, and water metering. Several kinds of documentation span these components, depending on the project's specific water-saving strategies [7].

3. Case Studies

The Army is familiar with the water reuse process on several installations many installations have been practicing water reuse at vehicle wash racks and for irrigation purposes for many years. The wash rack systems typically consist of sedimentation basins and oil-water separators, with additional technologies applied as needed to meet water quality for a given washing application and environmental protection. Wastewater reclamation is being used to irrigate golf courses and other large parcels have been achieved by providing a higher level of wastewater treatment. With the new Net Zero guidance being implemented across the Army, additional reuse opportunities will be pursued. Some representative examples of recent advancements are provided herein, but there are many other installations considering or practicing water reuse at various scales.

Fort Carson in Colorado has used this process to irrigating its golf course with treated wastewater since the 1970s. The reclamation system has recently been updated to expand the fraction of irrigation that is accomplished using treated wastewater to include other recreational areas. The goal is to use treated wastewater to offset approximately 200 million gallons of water demand each watering season.

Aberdeen Proving Ground has also recently started a project to reuse effluent water from a groundwater remediation effort to offset water demand at a boiler facility, which provides heating to buildings. The effluent water was previously being discharged to a local creek. The reuse project is expected to result in substantial cost savings compared to the previous local discharge practice. Tobyhanna Army Depot has implemented a water reuse process in its wastewater treatment plant. The process reused treated wastewater to support foam reduction processes that were previously supported with potable water. This saves 300,000 gallons per month and had a payback period of just over one month. The depot also implemented a re-circulating water chiller to save an additional 2,000,000 gallons per month.

One of the challenges with water reuse projects is the cost of retrofitting the associated infrastructure. At the building scale, for instance, re-plumbing the sink, laundry, and shower sanitary drain lines to a dedicated gray water collector and then re-plumbing distribution lines to supply low tier activities such as toilet flushing and irrigation is not very cost-effective in many cases. For centralized water systems, similar challenges can manifest when designing and installing a new purple pipe distribution network to support reuse activities such as flushing toilets in buildings. While there are certainly many scenarios where water reclamation or gray water reuse can pay back in an acceptable time period, there are ongoing efforts within the R&D community and even some cases that may help alleviate retrofit costs such that a greater fraction of water can be reused in an equally economical manner.

Several municipalities in the US have implemented more progressive water reuse systems that recycle wastewater for potable use. These Direct Potable Reuse (DPR) systems include advanced tertiary treatment technologies positioned downstream of the wastewater treatment plant for the control of pathogens and trace contaminants like personal care products. Component technologies can include reverse osmosis membranes for screening out the smallest of contaminants and advanced oxidation processes for destroying any organic contaminants. Coupled with frequent water quality monitoring and other quality control measures, these systems then return the purified wastewater to the head works of the drinking water plant or directly inject into a potable supply reservoir. Examples of DPR systems include Big Spring and Wichita Falls in Texas and Cloudcroft in New

Mexico. At the building scale, facilities with showers and laundry could potentially explore high tier reuse, or more appropriately, recycling of shower and laundry water to allow a greater fraction of the gray water to be recovered. While this requires a higher level of purification prior to reuse, the Army has developed gray water recycling systems for field use that could potentially support building scale recycling activities should regulations allow so in the future.

3.1. *Fixture scale reuse*

To alleviate the costs of retrofitting the plumbing system of an entire building, fixture scale reuse systems are also being developed. By reusing water within the fixture or bathroom itself, the retrofit costs may be potentially reduced. Shower stall products that recycle shower water and recover waste heat are being developed by several corporations around the globe. A demonstration at ERDC CERL is looking at a commercial scale under-sink water reuse system that uses sink water effluent to offset some of the toilet flushing demand. A residential model of such a technology was previously commercialized.

4. The City of El Paso and the Use of Purple Pipe

El Paso Water Utilities (EPWU), one of the nation's most progressive water agencies, has been delivering reclaimed water to the community since 1963. As a pioneer in water reclamation, EPWU has attained international recognition for its innovative and extensive use of recycled water. EPWU now operates one of the most extensive and advanced reclaimed water systems in Texas for industrial use and landscape irrigation [8]. Purple pipe can reduce the demand on the potable water treatment and distribution system. It also reduces the demand on water supplies such as surface or ground water sources and recharges diminishing groundwater supplies and may reduce saltwater intrusion into aquifers. Additional benefits are the reducing the volume on a wastewater treatment plant and its collection system and it reduces the volume of water discharged from the WWTP to the environment. It also provides a drought-resistant irrigation water supply.

The city of El Paso Texas has become a leader in the use of purple pipe because of necessity. The El Paso Water Utilities (EPWU) has established themselves as one of the nation's most progressive water agencies. EPWU has been a leader in water reclamation since 1963 and has been recognized international for its innovation and extensive use of recycled water. EPWU operates one of the extensive and advanced reclaimed water systems in Texas for industrial use and landscape irrigation.

EPWU has several currently under construction in the city will assist the city in harvesting rain water, the distribution, and will safe much needed water resources. One current project is a multi-phase project that provides over 520 million gallons of reclaimed water per year through 26 miles of pipeline to various locations throughout the city. The system is fully automated dispensing station, which operates continuously and provides uninterrupted service to contractors for construction, street sweeping, etc. This project is valued at $23 million paid for by grants from the U.S. Bureau of Reclamation, the Texas Water Development Board and through City of El Paso Water and Sewer revenue bonds from EPWU. Other projects that provided reclaimed water service to 3 schools, parks, cemeteries, municipal golf courses, and the city zoo for irrigation. In phase one of this project reclaimed water is distributed thru 19,200 linear feet of the purple pipeline infrastructure developed by EPWU to locations throughout Central El Paso. This purple pipe system also supplies water to five major cemeteries, three parks, a storm drain station, street parkways and medians. EPWU has constructed stations that dispense reclaimed water into water trucks for construction sites, street sweeping, car washing, and other non-potable uses. This project is valued at $13.4 million, which was also funded by the U.S. Bureau of Reclamation and through the City of El Paso Water and Sewer revenue bonds from EPWU and provides approximately 325 MG of reclaimed water per year.

Wastewater within the EPWU service area is collected and treated at one of four EPWU wastewater reclamation plants using advanced secondary or tertiary treatment. The result is high water quality that earned EPWU the reputation of operating the first wastewater treatment plant in the world to meet drinking water standards for its reclaimed water. The other three plants meet the highest possible quality rating of Type I reclaimed water as described in Texas state regulations and monitored by the Texas Commission on Environmental Quality (TCEQ).

4.1. *Current Projects*

One current project under construction is the Northwest Reclaimed Water Project. This multi-phase project provides over 520 million gallons of reclaimed water per year through 26 miles of pipeline to various locations in northwest El Paso. A fully automated dispensing station operates continuously to provide uninterrupted service to contractors and others for construction, street sweeping, etc. The project value is $23 million paid for by grants from the U.S. Bureau of Reclamation, the Texas Water Development Board and through City of El Paso Water and Sewer revenue bonds from EPWU. The city is planning extensions to service to serve new schools, parks, and commercial properties in more areas of the city.

Phase I of the Central Reclaimed Water Project was completed in 2003 and provides reclaimed water service to 3 schools, parks, cemetery's, municipal golf courses, and the city zoo for irrigation. The first phase of this project provides reclaimed water through 19,200 linear feet of pipeline to various locations in Central El Paso. The second phase extends as far as areas north of the city and services 3 parks, a storm drain station, street parkways and medians. This phase incorporates two automated dispensing stations into the system to provide continuous service for construction activities. These stations dispense reclaimed water into water trucks for construction sites, street sweeping, car washing, and other non-potable uses. The projects are valued at $13.4 million, which was funded through grants from the U.S. Bureau of Reclamation and through the City of El Paso Water and Sewer revenue bonds from EPWU and provides approximately 325 MG of reclaimed water per year [8].

5. Conclusion

Harvesting rainwater for irrigation of trees, grass, gardens and landscapes is a practice that assist in water conservation, mosquito prevention, and protection of water sources, reduces water runoff and pollution, and helps in sustainability. Harvesting and reclaiming rain water helps cities, military installations in the United States are conserving millions of gallons of potable water each year for domestic uses. When not filtered rainwater is non-potable and may contain high levels of salts and nutrients than potable water. The water has a higher contents of salts than potable water and these salts can accumulate in the soil with time if not managed properly. In communities like El Paso Texas the use of purple pipe to distributed harvested rainwater has become part of the city's infrastructure planning [8]. The city has devoted millions of dollars to collect and recycle water out of necessity. As a result El Paso has become a leader in the use of purple pipe to water city parks, golf courses, and various other municipal facilities.

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Severity Prediction Models of Falling Risk for Workers at Height

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Abstract

Construction industry has one of the highest accident and fatality rates among other major industries, with more than 60,000 fatal accidents each year worldwide. Falling from height is one of the leading causes of fatalities and injuries in construction. Passive protection devices (e.g., safety net) have been used to minimize the impact of falling from height for ages, while proactive warning systems appear recently to alert the workers when they are at risks of falling. To provide appropriate warnings to the worker but not to distract them due to the false alarm, the falling risk needs to be carefully evaluated. In this paper, the authors introduced algorithms for falling risk prediction and evaluated their performance. Injuries records during 2005 to 2015 were extracted from the OSHA database and 1161 intact falling-related record were used in this study. K-Modes, RBF network and Decision Trees are chosen to build three risk prediction models, and the performance of those three proposed models were evaluated using the OSHA injuries record data. The results indicate that the DT-based falling risk prediction model has the best performance of 75% and the top three critical factors of falling event's severity are distance from the ground, worker's occupation and the source of the falling. The delivered severity prediction model provides the foundation of more accurate real time risk evaluation for workers at height.

Keywords: Falling from height; machine learning; serverity of injury; risk prediction

1. Introduction

Safety is always a key issue in the construction industry. Due to the dynamic and hazardous nature in construction jobsites, enhancing safety awareness and investigating the nature factors for accidents cannot draw more attentions. According to the statistics from OSHA, there are 13,344 fatality accidents during 2005 to 2015, and 35.1% accidents related to the construction industry [1]. Correspondingly, the HSE statistics data also shows that construction accidents has taken a large proportion [2]. This indicates that construction safety is still a challenging task. Considering the causes of worker deaths on construction sites, falls, struck by object, electrocutions and caught-in/between are the "Fatal Four" causes, which is 36.5%, 10.1%, 8.6% and 2.5% respectively [3].

As the most fatal cause in construction accidents, fall from height in construction worksite has drawn lots of researchers' attention. Lipscomb [4] assessed the rate of falls from height over the 20-year period from 1989 to 2008 by using the Poisson regression. They found that younger workers had higher injury rates; older workers lost more working days for fall accidents, and the rates of patterns of paid lost days associated with falls decreased over time. Especially for fatal falls from roofs in the U.S. construction industry, Dong [5] investigated the trends and patterns based on records from 1992 to 2009. The study shows that roof fatalities accounted for one-third of fatal falls in construction during 1992-2009, and 67% of deaths from roof falls occurred in small construction establishments. In the study, the workers younger than 20 years and older than 44 years have the relative higher risk of roof falling fatalities. Kaskutas [6] investigated 13 kinds of commercially available fall protection devices, and designed a survey to measure workers' perception for these protection devices. According to Kaskutas' study, it shows that many workers believe these technologies can help them prevent falls but decrease their productivity. Chi [7] studied the causes for the falls and the accident events, and analyzed the influences of fall sites, company sizes, causes of fall and individual factors on construction fall accidents. It shows that there are primarily three causes for fall accidents: lack of complying scaffolds or protections, improper use of PPE, and bodily actions.

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Considering the fall accidents, these researches focused more on the cause analysis, and they have investigated the influence of working environmental factors relationship and individual information on such construction safety incidents through statistical methods. According to their research, it has been proved that the objective factors of the construction companies, such as: the economic strength, project scale, etc. or the construction workers' individual factors, such as: gender, age, work experience, etc. definitely can affect the occurrence of the construction safety incidents. However, their research primarily relies on the qualitative analysis, the influences and the relations of the features and factors are not accurately quantized. In order to investigate the direct causes of the fall accidents on construction sites for proactive protection and early warning, more deeply data mining and correlation analysis are necessary.

In this paper, three kinds of data mining methods are employed (Decision-tree learning algorithm, Artificial Neural Network, and Clustering algorithm) to analyze the OSHA data. 15 OSHA recorded parameters are considered for investigating their influence on the injury severity level. Through the importance analysis for the parameters and comparison of 3 kinds of data mining algorithms, the features for proactive fall injury protection on construction sites has been analyzed. The rest of this paper is organized as follows: in Section 2, the data scheme, parameters value scale and three data mining methods are described; in section 3, the preliminary results are illustrated; and finally conclusions and future works are described in section 4.

2. Data Source and Methodology

2.1. *OSHA Data Statistics*

This research is based on the OSHA inspection data, and focuses on the fall accidences in the construction industry which the SIC Major Group codes include 15, 16, and 17. All the data since Jan. 01 1984 with specified 15 parameters have been obtained, which the EventType is fall, and any record which has none or blank value of parameters are filtered out, and finally there are 1166 intact records for this research.

Each record of an injury data is composed of 15 parameters, in which all the values of EventType parameter are fall. ID is the short sign of the corresponding parameter. Class is the type value of the parameter and the Code is the code of the corresponding type value. Number of Cases record the number of cases in totally 1161 records and the Frequency denotes the occurrence ratio. There are totally 13920 records which obtained from OSHA database, however, lots of the values of record parameters are blank or not reported. All the records which have blank or not reported parameter values are filtered, and then all the small probability recorded event, which the probability smaller than 5% is filtered. Finally, there are 1161 intact fall injury records.

2.2. *Clustering Algorithm*

Clustering is a direct method to classify the data set. In this research, classifying the recorded fall of the injury data is a primary way to analyze the fall injury accidents data. Clustering is a rather diverse topic, and the employed algorithms greatly rely on the application scenario [8]. In this study, most of the parameters of the data set are the type of categorical data; however, for most of the clustering algorithms, they primarily process the numerical data. Therefore in this study, the k-Modes is employed. k-Modes is a k-Means based algorithm which can be used the similarity measure instead of the distance measure, therefore especially be employed in categorical data clustering.

In k-Modes clustering algorithm, set $X = \{X_1, X_2, X_3, \ldots X_n\}$ as a set of n categorical objects described by categorical attributes $A_1, A_2, \ldots A_m$. Then the mode of X is a vector Q that minimizes the following formula:

$$\mathrm{D}(X, Q) = \sum_{i=1}^{n} d(X_i, Q) \tag{1}$$

where d is a similarity function which in this study it is the Hamming Distance function, and the mode X is also the cluster center. The process flow of the k-Modes algorithm is described as follow:

Step 1. Divide the data set into training data and test data according to the training sampling ratio.
Step 2. Set the number of target clusters n, according to the Degree values.
Step 3. Divide the training data set into n clusters, according the Degree values.
Step 4. Select the mode vectors for clusters, according to equation 1.
Step 5. Process test data, calculate the Hamming Distance between the test data and mode vector of each cluster. Then the test data belongs to the cluster, from which has the minimum Hamming Distance.
Step 6. Add the new classified data into the cluster, and re-calculate the mode vector of this cluster.
Step 7. Return to Step 5 until all the test data has been processed.

2.3. *Decision Tree Learning Algorithm*

Decision tree is a non-parametric classification and prediction model organized in the form of a rooted tree with at least 2 levels, and at least 2 branches at one or more levels that have two types of nodes called decision nodes and class nodes [9]. Predicting the value of a target variable through learning decision rules inferred from the data features is the goal of the Decision Trees algorithms. The major advantage of decision tree is that it performs well even when its assumptions are somewhat against the true model. And in addition, it requires little data preparation and can handle both numerical and categorical datas. In this research the CART (Classification and Regression Trees) based Decision Tree algorithm is employed. CART does not compute rule sets and can construct binary trees using the feature and threshold that yield the largest information gain at each node.

Set the training vectors $x_i \in R^n, i = 1,\ldots, I$, and the target label vector $y \in R^l$. A decision tree recursively partitions the training vectors space and divides the training vectors with the same labels into one group. Let Q presents the data set of node m , then the impurity at m can be calculated as $H()$, and the total impurity of the decision tree is $G()$.

$$p_{mk} = 1/N_m \sum_{x_i \in R_m} I(y_i = k)$$

$$H(X_m) = \sum_k p_{mk}(1 - p_{mk})$$

$$G(Q,\theta) = \frac{n_{left}}{N_m} H(Q_{left}(\theta)) + \frac{n_{right}}{N_m} H(Q_{right}(\theta))$$

The p_{mk} is the proportion of class k observations in node m. In this research, the Scikit-learn Decision Trees algorithm package is employed, and the decision tree prediction is implemented in Python.

2.4. *Artificial Neural Network Algorithm*

Artificial Neural Network (ANN) is a classical machine learning algorithm. In order to implement proactive protection for fall injury in the construction industry, to investigate the factors or rules related to the fall accidents is definitely essential. Different from Decision Tree learning algorithm, ANN algorithm is totally based on the training data instead of the information entropy, therefore the learning ratio of ANN algorithms can reflect the consistency of the training data. That means if ANN algorithms can learn the data set well, then there must be some direct and constant rules for the data set. In another word, the behavior which is reflected by the data set has strong predictability.

In this research, the RBF network is adopted to learn the training data set. RBF network mainly is used in classification, time series prediction, function approximation and system control. For RBF network, the input layer is a vector of real numbers $X \in R^n$, and the output of the network is a scalar function of the input vector $\varphi : R^n \rightarrow R$, therefore a RBF network can be descripted as follow:

$$\varphi(x) = \sum_{i=1}^{N} \partial_i \rho(\|x - c_i\|)$$

Where N presents the number of neurons of the hidden layer, c_i denotes the center vector for neuron i , and ∂_i is the weight of the output layer neuron i .

For this research, the intent is to predict the injury level according to the recorded accidents factors. Therefore, the output of the RBF network is the injury level which can be presented by the Degree parameters, and the input of the RBF network is the vector which consists of the recorded accident feature parameters. Since the output of the RBF network is the R domain, the value of the output may be floating numbers. However, in this research, the output is the category of the degree, and it is a kind of categorical data. In order to map the output value of RBF network into the given categorical value, k-Means algorithm is integrated to process the output value of RBF network.

3. Preliminary Results and Discussion

3.1. *Features Importance Analysis*

OSHA offers detailed information for construction fall accidents, including the basic description, occupational information, time and causes. All the recorded parameters can be quantized for this research. There are 15 parameters, in which the Degree presents the scale of the injury level. The recorded event type (EventType) is fall. Therefore, the Degree value is employed as the label of the data records in this research.

For investigating the influence of the parameters on the injury degree prediction. First, the importance of the parameters has been analyzed. Based on the Gini importance theory [10] and the mRMR algorithm [11], the importance of the parameters is calculated and the results are illustrated in Figure 1. Gini importance and mRMR are two classic features selection algorithms. These two algorithms can calculate the importance of features for classification, in which the larger importance value, the more influence for the classification.

As the illustrated results, the Occupation, FallDist and PartBody are the most 3 important parameters both in Gini importance analysis and the mRMR algorithm. For EventType parameter, it shows that the importance is 0 in the all situations. It is because that in this research the fall accidents are focused on, all the EventType values are fall. If just considering the injury degree, it shows that Occupation, FallDist, SourceInjury, and PartBody, the 4 parameters contribute most to the classification.

3.2. *Data Mining algorithms based Injury Severity Prediction*

Based on the OSHA data, one fall accident is an abstract record described by 15 features. According to the analysis in section 3.1, PartBody, FallDist, Occupation, and SourceInjury are the top 4 important features for classifying the data set into different injury degrees. The accuracy of the three types of classification algorithms has illustrated in Figure 2.

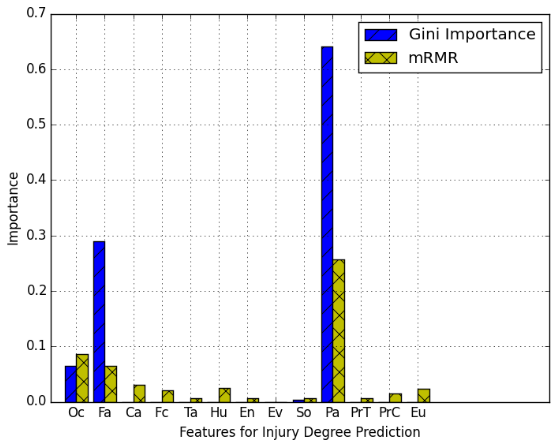

Figure 1. Features Importance Analysis for Injury Degree Prediction

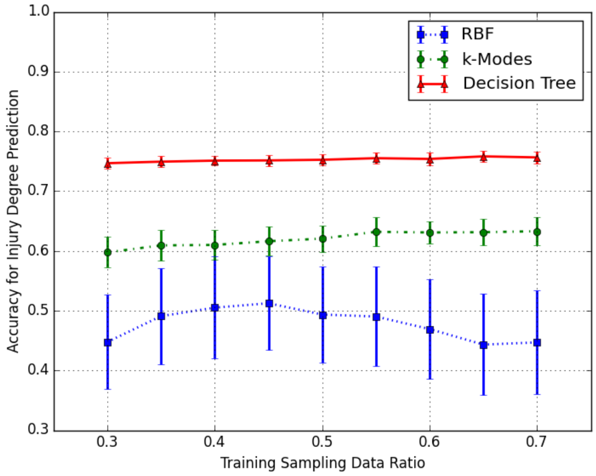

Figure 2. Training Data Ratio VS. Prediction Accuracy for Injury Degree

For the k-Modes algorithm, the value of the Degree feature is the label of the records and the k-Modes output. The value of the most relative features composed of the feature vectors and the input of k-Modes algorithm. Through learning the relation rules, the k-Modes algorithm predicts the injury degree according to the feature vectors. The k-Modes algorithm can generally achieve 0.62 accuracy.

RBF network also employed the most relative 4 features as the input vector, and the output is the degree of injury. Although generally RBF network is a good kind of ANN algorithm for classification, in this research, it can only achieve up to 0.49 accuracy for injury degree prediction.

Decision Tree algorithm based on the Gini importance theory to process the data vector. Based on the analysis in section 3.1, the top four important features were selected. Therefore the feature vectors can achieve the maximal Gini importance. Its accuracy for injury degree classification is around 0.75.

4. Summary and Conclusions

In order to investigate fall injury proactive protection for construction industry workers, this research studied the OSHA data. Two parameter analysis methods: Gini importance analysis and mRMR algorithm were employed to analyze the importance of the data features, and 3 kinds of data mining algorithms DT, k-Modes, and RBF network were applied to classify and predict the degree of the injury. By comparing the accuracy of the 3 kinds of algorithms, the DT algorithm definitely has the best performance for the injury prediction. According to the importance analysis, the injured part of the body (PartBody), fall down distance (FallDist), worker's occupation (Occupations) and the source of the injury (SourceInjury) are the top 4 important parameters for injury degree prediction.

In conclusion, to a certain degree, the fall accidents in construction can be predicted, and the data mining algorithm, especially Decision Tree algorithm can do further contributions for fall injury proactive protection. In addition, according to the importance analysis and prediction comparison, just depending on the objective features of the construction company or construction workers to predict the construction injuries is definitely a reluctant method. In order to offer proactive protection, monitoring the position and posture of a worker, which can be relative to the FallDist and PartBOdy features, in real time is significant. This could be our future work.

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Energy Efficiency Housing in South Australia – A Gap Analysis between the Expected and Actual Benefits

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Abstract

In Australia, the trend of being energy efficient within modern multi-storey buildings has been more popular in recent years. However, lack of attention has been given to the residential housing in terms of the perceived benefits and actual performance. The purpose of this research is to investigate the gap between the original expectation and the occupants' satisfaction in residential energy efficient dwellings. This research also aims to analyze the relationship between the satisfaction level and both the initial as well as the ongoing cost of energy efficient dwellings in South Australia. Finally, it determines whether the initial cost of residential green building is proportional to the financial savings. The research methodology comprised a literature review and data collection through the use of questionnaires. The literature review provides a background of knowledge that has been studied on green buildings. The findings of this research have indicated that South Australians were satisfied with the perceived benefits of the residential energy efficient buildings since occupation. However, the higher up-front cost has brought the households various concerns including their affordability and actual financial savings. The major benefits that are brought by energy efficient housing including reduced in energy cost and consumption, and improved thermal performance. Through the gap analysis, a positive outcome has been found, indicating that actual performance of energy efficient housing is exceeding the users' expectation. It is suggested that the State Government as a leader of the energy efficient housing promotion needs to provide more financial incentives in order to disseminate the housing option while moving towards a sustainable future. Meanwhile, the local builders need to improve their understandings on energy efficient housing, while providing more energy efficient housing options to the South Australian market.

Keywords: Energy efficient housing, green buildings, South Australia

1. Introduction

The concept of sustainable development has been advocated since late 1980s and the idea of building green in order to respond to the call of achieving sustainable development was first brought up in the "Architects' Chicago Declaration" during the International Union of Architects Congress in 1993 [1]. The Green Building Council Australia (GBCA) was found in the year of 2002 in order to response the need of encouraging and promoting the green building practices across the country as a not-for-profit organisation. There are many research articles which focused on investigating the benefits and barriers of commercial green building design and construction since then [2, 3, 4, 5]. However, less attention has been given to the residential sector. Limited investigations have been conducted to look into the residential housing especially in South Australia regarding to the perceived benefits and actual performance. In fact, both 'residential and commercial buildings in Australia are responsible for 23 per cent of the nation's greenhouse gas emissions' [6]. Hence, there is a need to investigate the current development of green building practices in terms of the perceived benefits and actual performance in the residential sector.

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1.1. *Why do we need green building?*

Global warming which is mainly caused by the greenhouse gas (GHG) emissions has brought up the public's attention in recent years. Extreme weather condition as a major side effect of global warming has been accounted for huge financial cost in Australia. The Parliament of Australia 2013 has found that total financial estimated cost of extreme weather events in Australia ranging from approximately 900 million dollars to 4 billion dollars annually. Furthermore, 'climate change can significantly impact on the total energy consumption and GHG emissions of residential buildings [7]. In 2005-2006, the residential building sector in Australia contributed around 13 per cent of the total national GHG emissions [8], and the energy demand is anticipated to keep rising due to '… the projected population growth, the trend of smaller family sizes, and the desire for more comfortable indoor environment and larger houses …' [9]. Hence, there is an urgent need to be green in order to mitigate and adapt the climate changing climate.

1.2. *Benefits and barriers*

Building green architectures is a way to respond to the climate issues. The most significant advantage that is brought by green building is to reduce the overall energy consumption and cost as well as to enhance the occupants' satisfaction through the incorporation of building design, materials selection and construction delivery [9]. Ries et al. [10] further proved that green building can bring positive impact on the occupants' health and productivity, indoor environmental quality and consumption level of energy resource. However, there are barriers that need to be considered when promoting green buildings. A Swedish paper which focused on investigating the cost of going green has shown that the overall cost can be a concern. Although the difference of total investment cost between residential green building and conventional housing is said to be less than 10 per cent, the cost of design, materials and labour for the green ones tend to be approximately 10 per cent higher than the conventional ones [11]. When there are design variations or market fluctuation, all costs will increase and hence the residential green building will become less affordable. While the saving of operation cost in green building can be up to 20 per cent - 40 per cent, '… achieving the estimated energy efficiency may require more system adjustment than usual' [11], and this has posed a challenge as in balancing the system. Occupants may be frustrated by the above benefit issues. The installation of an appropriate individual metering system for data collection within each household has posted another significant expense to the cost. To sum up, there are uncertainties that lie in the calculation of the total cost.

Occupants' behaviour and understandings directly contribute to the level of energy consumption, which is also the actual performance of the green building. Gill et al. [12] commented that 'whilst behavioural change is a major untapped route for energy savings, the varying knowledge, attitudes, and abilities of occupants presented a fundamental barrier to its implementation and optimization'. When occupants' behaviour is not ready to adapt the green practice, it is less likely to achieve the target of reducing the energy consumption.

2. Green Buildings in South Australia

South Australia has promptly responded to the trend of being green in building development. In 2002, Premier Mike Rann announced the launch of Lochiel Park Green Village and stated that the project will become the nation's model [13]. The project is delivered by the Urban Renewal Authority URA (formerly Land Management Corporation), and it is to exemplify the objective of 'Attaining Sustainability' in the South Australia's Strategic Plan (Campbelltown City Council). The project will undergo a 9-year long monitoring program to analyse real time data of all energy consumption in the households throughout the period [13]. There are other upcoming green residential projects including the redevelopment of Tonsley and Bowden which were announced by the Renewal SA in 2013. Both of the projects will be assessed against the Green Star rating scheme which is monitored by the GBCA [6].

2.1. *Green affordable housing in South Australia*

Cost and affordability is considered as a combined critical factor which influences people whether to build, rent or renovate a dwelling regardless of whether it is an energy efficient or conventional one. In South Australia, providing affordable and energy efficient housing has been listed as one of the seven strategic priorities of the State. The State Government has then further addressed the importance this type of housing through the publication of the South Australia Strategic Plan in 2011. According to the Plan, the State aims to '… lead the nation over the period to 2020 in the proportion of homes sold or built that are affordable by low and moderate income households', while improving '… the energy efficiency of dwellings by 15 per cent by 2020' [14]. Furthermore, Renewal SA, which is established an official organisation is '… responsible for increasing the supply of housing that is affordable so that South Australians have opportunities to live where they want at a price they can afford' [15].

Nevertheless, it is not easy to identify how to produce affordable housing with energy efficient elements featured within. Boehland [16] outline the considerations that apply to all affordable housing, these including location; the costs of initial, operations and maintenance; health and safety of environment, and; occupant's satisfaction. Blaess et al. [13] stated that 'the cost of living sustainability can be high due to the initial lack of volume in the market for some of the new technologies and upfront cost premium'. In terms of initial cost, Tollin [9] stated that the investment premium involved in green building could range from less than two per cent to more than ten per cent when compared to the costs of conventional construction. In 2009, a cost analysis was conducted to study the cost of green for affordable housing in the cities of Seattle and Portland in America. The result of the analysis has shown that there was a 4.6 per cent difference in construction cost in average between the green-rated buildings and standard buildings [17]. Occupants of green housing may not need to face the direct impact of the extra cost if receiving subsidise from the government, however, '… higher first cost reduce the number of affordable housing units completed' [16]. In fact, Australia as one of the leading developed countries is still facing housing affordability problem. In the year of 2008, the Labour Government commented that housing affordability dropped an all-time low [18]. The situation was then improved, and according to the latest "HIA-Commonwealth Bank Affordability Report" which was released in March 2014, the affordability index maintains a positive grow compared with the figure recorded a year ago [19]. However, the Report pointed out that the improvement is '… largely due to much more lower interest rates, growth in earnings, and relatively muted home price inflation…'. It should be noted that the influencing factors will not always stay in place since the performance of the economy is unpredictable. Once the favourable factors are ceased, the price of housing may not be affordable. Funding from the government to provide affordable housing to households will become necessary in this case, however, energy efficient features may not be included within due to the extra cost as previously mentioned. The features is no longer to be the priority anymore, in other words, they are not "needs" but "wants". Hence, it is deduced that green affordable housing is still facing a financial barrier in term of broader promotion.

2.2. *Post-occupancy evaluation*

According to Zimmerman and Martin [20], the earliest definition of post-occupancy evaluation (POE) can be traced back to 1980, and at the time POE was regarded as the assessments of the effectiveness for human users of occupied design environments. Hua [21] and Meir et al. [22] defined POE that it is a process and platform for systematic evaluation and studies of the performance of buildings during the occupation stage of a building. It should be noted that the emphasis of a POE is not to collect technical data and performance of a dwelling; instead, it is more of a user-perspective based assessment tool. The feedback from the occupants will be used for improving the current living environment within the building as well as guiding the future building developments which are of the similar nature. Generally, a POE would include the aspects of thermal comfort (including ventilation, heating ,and cooling); illumination and visual comfort; occupants' satisfaction and behaviour; physiological and psychological comfort; health and safety; aesthetic quality of building; and identification of system defects. The general tools and methods that can be used for conducting a POE including surveys, questionnaires, cohort studies, observations, task performances tests, and document analysis [22].

The GBCA [23] has suggested that a dwelling can be green through a range of initiatives and technologies as cited below:

1. Passive design;
2. On-site generation of energy from renewable sources;
3. Efficient appliances and light fittings;
4. Purchasing green power;
5. Introducing alternative ways to learn; and
6. Optimising, upgrading or removing HVAC systems

In order to investigate the various aspects including the users' satisfaction in accordance with the occupied buildings' functions and performance after implementing the above strategies, post-occupancy evaluation (POE) is sometimes carried out for the purpose of further study. Nevertheless, the perceived benefits which are brought by the above implications have not been fully assessed against the users' satisfaction and the ongoing cost in depth in Australia.

Meir et al. [22] conducted a synoptic overview of POE studies. There were total 58 papers found which involved the use of POE. However, only seven of them were related to the residential sector, indicating that not much attention has been given to the users' response from the residential sector. The POE studies of those seven papers were conducted in different countries, including the Israel, Japan, Scotland, United Kingdom, and United States.

3. Research methods and analysis

The aim of this study was to carry out a gap analysis between the expected and actual satisfaction of energy efficient housing from the point of view of occupants in South Australia. University Ethics approval to conduct data collection from target audience has been obtained prior to the invitation. The potential respondents were sourced from the occupants who were living in energy efficient dwellings within Lochiel Park [24]. Respondents were invited to complete the questionnaire throughout personal home visits. The total number of energy efficient houses built in Lochiel Park was 72. 45 surveys were completed, representing a total response rate of 62.5 per cent.

The respondents were asked to explain about their decision on purchasing an energy efficient house. According to their replies, the biggest momentum that inspires the respondents to purchase an energy efficient house is "to support environmental sustainability", followed with, "to improve quality of living, occupational health and safety, and productivity", and "to adopt the green philosophy". Financial factors including affordability and future investment value were the least chosen answers from respondents influencing their purchase decision. From the cost perspective, 84.44 per cent of the respondents noticed that there is a significant price difference between energy efficient and conventional housing. It includes the additional cost on the choice of construction materials, architectural designs and the energy efficiency appliances. The total could easily amount to extra of $100,000 and more.

The following Table 1 illustrates the various levels of satisfaction with respect to each individual question by a likert scale of 1 (very dissatisfied) to 7 (very satisfied).

Table 1. Summary of levels of satisfaction to research questions

very dissatisfied	dissatisfied	slightly dissatisfied	Neutral	slightly satisfied	satisfied	very satisfied
1. Respondents' satisfaction level after occupying in energy efficient housing while considering the overall performance and cost						
0.00%	0.00%	0.00%	2.22%	2.22%	46.67%	48.89%
2. Is energy efficient housing a satisfying (worthwhile) investment in long run considering the overall performance and cost						
0.00%	2.22%	0.00%	4.44%	4.44%	35.56%	53.33%
3. The respondents' original expectation towards energy efficient housing						
0.00%	2.22%	0.00%	13.33%	24.44%	53.33%	6.67%
4. The respondents' satisfaction towards energy efficient housing after occupation						
0.00%	0.00%	2.22%	2.22%	6.67%	55.56%	33.33%

Compared to the conventional houses that the respondents previously lived in, the majority of respondents have noticed that there are tangible differences in energy consumption, between conventional and energy efficient dwellings. Respondents who have noticed the presence of differences were then asked to select the aspects of differences that they have experienced within their energy efficient building. Amongst all the differences, the energy performance of their energy efficient home in terms of cost and consumption are considered to be the most obvious improvements that can be identified. Furthermore, improved thermal performance is also an area that has been addressed by the respondents.

After having a basic review on the cost and dwelling performance issues, the survey then combined the considerations of cost, performance and living experience together. The respondents were asked to rate their satisfaction based upon the above considerations. There is a clear stance of the majority respondents that they were very satisfied with their energy efficient homes while considering the overall cost and performance. The options of "very satisfied" and "satisfied" were mostly rated, representing a combined percentage of 95.56 per cent. None of the respondents had any negative views on the current living dwelling as no count was recorded for all negative options including "slightly dissatisfied", "dissatisfied" and "absolutely dissatisfied".

When it comes to the question of whether energy efficient housing a worthwhile investment in long run considering the overall performance and cost, 88.89% of respondents indicated that it is still a worthwhile investment. However, negative comments were also found, including "(the respondent's home) has not performed as well as expected", "not much saving if you consider the (up front) investment (cost)", and "not (worthwhile) as a rental (option)".

In order to further investigate the difference between expectation and level of satisfaction of their energy efficient housing, the respondents were asked about their expectation before and satisfaction after moving into their energy efficient homes. According to the Table 2 below, majority of respondents had high level of expectation towards energy efficient dwelling before occupation, and high satisfaction were recorded after occupation. The recorded scores of both expectation and satisfaction level were used to produce a mean score for each level. A gap difference of 0.69 is shown, representing a small and positive change in satisfaction level.

Table 2: Gap analysis between the original expectation and satisfaction after occupation

Answer Options (expectation)	No.	Mean	Answer Options (satisfaction)	No.	Mean
Absolutely no expectation	0	0.00	Absolutely dissatisfied	0	0.00
No expectation		0.04	dissatisfied	0	0.00
Slightly no expectation	0	0.00	Slightly dissatisfied	1	0.07
Neutral	6	0.53	Neutral	1	0.09
Slightly high expectation	11	1.22	Slight satisfaction	3	0.33
High expectation	24	3.20	Satisfied	25	3.33
Very high expectation	3	0.47	Very satisfied	15	2.33
	45	5.47		45	6.16

4. Conclusions

The results of questionnaire show that the occupants of Lochiel Park who participated in the questionnaire survey tend to pursuit a sustainable and quality living life style. Meanwhile, the financial factors are not considered as the most influential factors affecting the purchase decision of the energy efficient house. There is an obvious cost difference between conventional and energy efficient housing. While the majority of survey respondents believe that the cost difference can be more than a hundred thousand dollars, the selection of construction materials, installation of energy efficient appliances, and architectural design of energy efficient housing are considered to be major factors that increase the investment cost in advance. The respondents realise that there are tangible differences in the aspects of reduced in energy cost and consumption, thermal performance, lighting and general living experience. Considering the overall performance and cost, the majority of respondents have a positive stance that energy efficient housing is a worthwhile investment in long run. There is a shift indicating that those who had a relatively neutral and slightly high expectation to energy efficient housing, move toward a more satisfied attitude after occupation. The gap analysis has reflected that there is a minor positive difference between the expectation and satisfaction level before and after occupying in energy efficient dwelling. Finally, most of the respondents look forward to promoting the energy efficient housing as a future housing option to family and friends. The respondents from the home visits agree that it is important to be energy efficient in order to reduce environmental impact as well as to achieve a sustainable future. The positive phenomenon has provided a solid foundation to support the broader promotion of residential green building in South Australia. However, since the higher up-front cost is considered as the major barrier for the broader promotion, more financial incentives from the State Government are needed in order to attract the low income households as well as those who have a relatively low interest in environmental issues. Otherwise, it will not be affordable. Meanwhile, the government needs to educate the public about energy efficiency with actual facts and numbers gathered from the existing energy efficient dwellings. This can improve the public's interest while providing a momentum for South Australians to move towards a sustainable future. On the other hand, some builders were not able to answer the owners' inquiries regarding the energy efficiency, and many believed that the builders did not fully demonstrate their professionalism due to lack of experience. This has reinforced the importance of additional training and education to the builders.

Whilst South Australians agree that it is important to be energy efficient in order to reduce environmental impact as well as to achieve a sustainable future, this research has found that up-front cost is still the major barrier precluding many South Australians to choose energy efficient housing as a potential housing option. It is necessary to further investigate the factors which cause the cost difference, and hence, to determine suitable strategies to reduce the differences. On the other hand, there are uncertainties regarding the actual financial savings that energy efficient housing can provide to the households in a long run, there is a need to conduct further research on how the uncertainties will impact on the actual financial savings.

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Reducing Operational Costs for Inherited Buildings: Case Study of a Women's Shelter at the End of its Life Cycle

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Abstract

Obstacles faced when utilizing adaptive reuse for an old building located in a poverty-stricken high-crime area are numerous. This study evaluates the effectiveness of adaptive reuse and recommends best practices for facility operation and maintenance. To evaluate the effectiveness of adaptive reuse in the case of a women's shelter, the investigators used five data collection methods: literature review, building assessment, resident surveys, staff interviews and utility record analysis. This research revealed that the shelter did not choose the most effective facility to adapt and reuse for their growing needs. The facility meets the basic necessities of the shelter; however, sustainability of this adaptive reuse effort remains poor. High utility costs, excessive repairs, and several opportunities for heat loss in the building have severely reduced operational efficiency and prevented optimal use of funding to benefit women in need. Structure analysis combined with expected need would better serve those embarking on a project to effectively utilize a preexisting building to its optimal potential rather than building new to exact specifications.

Keywords: adaptive reuse; construction; cost; operational cost; sustainability

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1. Introduction

The women's shelter is surrounded by the city transportation department, a museum, an elementary school, a few small restaurants, and convenient stores. The building is located in a poverty-stricken high-crime metropolitan area. It is an adaptive reuse facility with building repairs in excess of $100,000 and counting. Most of the women who have needed the assistance of this shelter in the past have been senior citizens experiencing homelessness. The facility depends primarily on donations; however, even with the donations they receive, high utility costs limit the impact of funding and the potential to effectively benefit a greater number of women requiring basic shelter needs.

The shelter failed to assess significant structural considerations in view of the current facility for the intended purpose when it was inherited. Failure to recognize the key considerations in analyzing and assessing the deterioration of the structure have adversely affected both staff and those seeking refuge within the shelter. Reducing operational costs by further analysis of the current structure would aid in development of a cost savings plan as well as pinpoint other needs not otherwise considered. This would lend itself to a proactive situation rather than the current reactive approach utilized by residents and staff. The shelter could potentially reduce their operational costs by effectively assessing the building and implementing a structured adaptive reuse approach. Specific strategic modifications could potentially reduce building maintenance and operation costs creating increased opportunities for growth and wellbeing.

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2. Literature review

Common nomenclature used for adaptive reuse can be misleading. According to Holyoake and Wyatt [8], reuse can mean something special, unique, and often expensive while adaptation describes rehabilitation, renovation or restoration works that do not necessarily involve changes of use. Unlike restoration, adaptation does not restore a building to its original state, instead adaptation “retains as much as possible of the original building while upgrading the performance to suit modern standards and changing user requirements [9].” Adaptive reuse, as defined by Douglas [6], is any building work and intervention to change its capacity, function or performance and adjust, reuse or upgrade a building to suit new conditions or requirements.

With investment cost of renovations and repairs mirroring, and in some cases exceeding new construction investments, the design and construction industries are looking at a huge shift. Although there is still a demand for new construction, “the market is overbuilt;” therefore, most of the construction within the next decade will consist of renovations and adaptive reuse projects on the existing building stock [5]. Bullen [2] supports and highlights the fact that new construction only accounts for 1.5-2% of the existing building stock in developed countries. Within the next 25-years, the majority of the work procured will most likely include improvements on the existing building stock [1]. This trend is prompted and accelerated by the growing need to preserve natural resources and reduce energy use and greenhouse gas emissions [2].

According to Spector [10] as referenced by Bullen and Love [3], there are seven major considerations that should be factored into the decision-making process for adaptive reuse building selection. The suggested considerations include the following: Layout, Energy Efficiency, Potential Requirements, Condition, Hazardous Materials, Building Safety and Security, and Location [2]. There are several reasons that may propel an owner to prefer demolition as opposed to adaptation [3, 4]. These reasons include: “the building reaching the end of its service life; reduction of the building’s usefulness over time; the building becoming out of fashion and out of date; deterioration of the fabric or structure; reduction in efficiency coupled with increased expenditure to keep the building operating; reduction in ability to meet the demands of occupants over time; population movements either increasing or decreasing; and prolonged vacancy rates [3].”

To increase a buildings viability for adaptive reuse, it is suggested that owners and stakeholders conduct an in depth analysis of the site, structure and shell, division of interior space, materials and components, technologies, archival documentation, style and durability of the building [1]. It has been proven that adaptive reuse is sustainable for the environment; however, the underlying concern that ultimately serves as a catalyst for people to buy into this concept is the financial costs of adaptive reuse projects. According to interviews conducted by Yung and Chan [12] “the economic viability of the new operating use has been the key hurdle to successful adaptive reuse. Compared to standard reuse projects, sustainable adaptive reuse projects tend to be 12% more expensive [7] yet “an adaptive reuse strategy is only preferable to demolition if the objectives of environmental sustainability and reduced energy consumption can be attained [11].”

Ongoing maintenance costs pose as one of the largest threats to the economic efficiency of a building and are a consideration that spurs owners to prefer demolition and reconstruction or new construction in lieu of adaptive reuse [3]. Likewise, every building is not suitable for adaptive reuse. In fact, “several architects suggested that buildings reach a point in their life where they cannot be adapted anymore and demolition is the only solution” [3]. When the intangible, though not easily measured, and tangible benefits of a project are found to be greater than the initial investment, economic efficiency is achieved [12].

3. Methodology

Both quantitative and qualitative data were collected during this study. The researcher employed five data collection methods to procure the following results and findings. Those methods employed included: literature review, building assessment, resident surveys, staff interviews, and utility record analysis. Direct inspection of the structure was completed. Interior and exterior components of the facility were assessed and included but were not limited to the windows, entryways, roof, mechanical systems, and organizational layout. Other considerations focused on heat loss with utilization of thermal imaging equipment to better identify specific areas of the building which negatively impact cost savings. The thermal imaging camera used was a Fluke® Ti32 (Everett, Washington – USA) selected for its accuracy, durability, portability, capability in both visible and infrared wavelengths, and on-screen emissivity correction and reflected background temperature compensation. Imaged data was analyzed by using the Fluke SmartView® 3.5 software. By analyzing the data obtained, the researcher was able to detect significant relationships between different variables and offer suggestions regarding potential areas to focus immediate attention in an effort to reap the most benefit for minimal cost.

4. Results and findings

4.1. *Shelter history*

According to the program director for the women's shelter, most of the buildings located on the shelter's campus were built in 1942. The main building, which houses all of the shelter's operations, was built in 1950. Originally, this campus served as the area's first low-income apartment community. The campus was then transformed into a place for disabled children of military families and temporary housing for the visiting military family members. Mental health purchased the property in the 1990s and the facilities were redefined as an establishment for the mentally ill. This transition resulted in the adaptation of several rooms into rooms functional for hospital care. When the government shut down 85% of the mental health facilities in Alabama, the facility was closed and the campus was vacant for one year. In 2013, the campus was purchased by a local church and transformed into a shelter for homeless women and their children.

The campus was purchased with the expectation that all buildings would be used to house homeless women and children. However, soon after the campus was purchased, the sprinkler systems malfunctioned and flooded several of the buildings. This accident caused tremendous damage to the buildings and hindered the staff from using the facilities to their full capacity. Currently, several of the buildings are either used for storage or are completely vacant and abandoned.

4.2. *Site observation*

The main building, the focus of this study, was oriented north to south. The front street-facing façade of the building faces north. Using Google Earth images, the researcher calculated the approximate square footage to be 16,200 square feet for the base level. The facility (Figure 1) housed 12 total apartments: two apartments used for single women, one apartment designated for onsite staff housing and the remaining nine apartments used to house single-mother families. In addition to these apartments, former medical-examination rooms were adapted and transitioned into overflow rooms for emergency situations and wait-listed applicants.

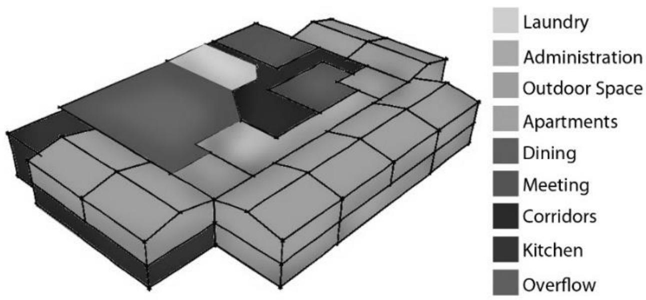

Figure 1. Interior Layout Diagram

The buildings are comprised of load bearing concrete masonry unit walls and a steel roof framing system clad with an array of materials including: aluminum, asphalt, and a rolled roofing material. Overall, the building looked worn on the exterior. The window systems were extremely dated single-pane systems with minimal caulking, several cracks and defects, and rust accumulation on the sills was observed.

The administrative areas included office spaces for the: case manager, assistant program director and the program director. These areas were located in the front of the facility and were high-traffic areas with usual activities like: donation drop-offs, resident arrival and departure, social activity and more. This space was often directly exposed to outside elements due to it being a high-traffic area. A community dining area also served as a place for residents to: eat, read or engage in other low-impact activities.

The multi-family communal aspect of the shelter posed difficulties for leadership in regards to maintaining physical organization. A lack of organization in the shelter negatively impacted operating efficiency. In the community room, chairs play pens, tables, and the like blocked active wall-mounted air returns. Damaged window treatments within the facility reduced the effectiveness of blocking the sunlight into the space. Uncontrolled light entered the building and solar heat gain for the space increased. Architectural defects in the building limited the effectiveness of the small organizational changes that needed to be made within the space. The building had several window penetrations for pieces of outdated equipment like window air conditioning units. These units were inoperable and only served as opportunities for heat loss throughout the space.

Acoustical ceiling tiles were missing with this ceiling defect exposing old fiberglass batt insulation. Gapped insulation could be contributing to heat loss within the space as well. In conjunction with the window units and insulation problems, there were resident induced weaknesses in the facility. Residents utilized floor model fans throughout their rooms—some which had more than one portable fan. One resident explained that the room temperatures were occasionally too hot for some of her roommates so the fans were used to cool the space. Cables were wired through windowpane defects. In an attempt to reduce the draft that this unconventional wire routing may cause, the resident applied duct-tape to the window.

Thermal imaging of the main areas demonstrated heat loss near the perimeter of the building with an almost 10-degree temperature difference from the interior spaces to the perimeter spaces. Infiltration through the doors caused by the open space at the base of exterior doors, window glazing, exposed exterior duct work, inoperable window units and gapped insulation served as major areas of heat loss for the facility. Dated mechanical systems were not functional to meet the minimal load to effectively heat and cool the structure.

4.3. *Utilities*

4.3.1. Gas

For the gas bill, the records ranged from April 2014 to August 2015. Over this 16-month time period, the average gas bill totaled $576.99 ranging from a minimum of $217.17 to a maximum of $1,466.60. The maximum gas usage during this time period took place in the period ranging from December 2014 to January 2015 with 1319 (100's of cubic feet) used. The lowest gas bill was recorded in the billing period ranging from June 2015 to July 2015 with 169 (100's of cubic feet) used. Further analysis demonstrated gas usage increases while power usage decreases during the colder months and gas usage decreases while power usage increases during the warmer months. Furthermore, according to the weather history and the utility data, the following trends unveiled: on average, gas usage decreases by 53% on cooling degree-days whereas gas usage increases by 202% on heating degree-days. There are several factors to consider. The lower gas usage may be the result of fewer residents in 2015 as opposed to 2014, a change in equipment, and/or more efficient use of gas.

4.3.2. Water

The utility records for water were gathered for twelve consecutive months ranging from January 2014 to December 2014. During this time period, the average water bill for the shelter totaled $672.56 with an average water consumption of 93,250 gallons. The peak water usage occurred in January with water consumption reaching 112,000 gallons and the utility bill cost of $784.62. The least water usage occurred in the months of November and December 2014 with water consumption being 77,000 gallons and the utility bill cost of $576.41. There seemed to be no apparent trends in water usage for the women's shelter no significant relationship between water and electric. A significant relationship between water and gas may be present in the shelter and this could be attributes to the use of gas water heaters.

4.3.3. Electricity

Due to the lack of consistency in the on-file records for this utility, the researcher was only able to analyze and track power usage trends for seven consecutive billing periods for each year that the current facility has housed the women's shelter. Consequently, the researcher evaluated the utility records for the billing periods ranging from February - March to August – September for the years 2013, 2014 and 2015. The lowest power usage during this time period was documented in the billing cycle from April - May in 2013 with an average daily kWh usage of 199 kWh. The highest power usage was documented in the billing cycle of July to August in 2015 with an average daily kWh usage of 1084 kWh. The year 2015 on average has proven to have the most power usage with an average daily kWh usage of 20,846 kWh as compared to 20,526 kWh in 2014 and 14,503 kWh in 2013.

4.3.4. Combined utility analysis

Because of the sporadic availability of the archival utility records for gas, water and power, the researcher requested an overall financial listing of utility costs for the shelter from the time the site was purchased by the shelter. In the year that the facility was purchased, the shelter spent approximately $47, 989.94 on utilities. In 2014, the utilities amounted to approximately $50,337.49 and in 2015 (from January until November) the total utility costs amounted to approximately $45,302.59. Based on these records, the average monthly utility cost for the women's shelter is approximately $3,340.23 with the utility cost per square foot averaging $0.21/sf. Overall, it is difficult to use the financial information from 2013 due to the fact that the shelter was purchased in this year and was not used to its full capacity until later into the year. Nonetheless, if the shelter continues the utility increase trend of 7.4% that was shown from 2014 to 2015, monthly expenses will amount to an average of approximately $4,865.50 in 2016. When looking at the seven-month snapshot from February to August, power usage at the women's shelter seemed to trend upward. Overall, the financial expenditure evaluation revealed the same trend in power usage.

4.4. *Staff Interviews*

The women's shelter had five women on staff at the time of the interview recordings. Interviews revealed that the average staff member had been employed with the shelter four months and only 1 out of 5 of the staff members were present when the building was inherited. According to her account, when the building was purchased "the building was left completely full of everything that Mental Health didn't want." In addition to housing the left-overs from the previous tenant, the building "had been vandalized and a lot of the heating and air units had been stolen. Most of the plumbing didn't work. The whole building needed to be painted. Everything had to be cleaned. There was no stove, no fryer, no refrigerators, no anything like that to keep food in. No blinds on the windows, a lot of the windows were broken out. It had been an empty vacated building."

Even with the complaints about the facility, overall, staff members were somewhat satisfied with the facility when it comes to maintenance requirements, monthly costs, etc. Three out of the five staff members were neutral in their level of satisfaction with the facility. One Staff member stated that she was somewhat satisfied, while the last staff member stated that she was very satisfied. However, the main reasoning behind the more satisfied staff members' responses revolved around merely being thankful to have a facility whereas the neutrally satisfied staff members mainly expressed that their neutrality could be attributed to the many maintenance and repair issues that the facility presents. The interviews also revealed that generally, staff members are not aware of the more specific requirements of the building, but they are generally well aware of the state of the facility and the more general requirements.

During one of the staff interviews, a staff member expressed her concern with the fact that they shared the same neighborhood with the "drug dealers and prostitutes" of which many of the residents were formerly associated. In light of these kinds of security issues and social failures, the women's shelter failed to fully thrive socially. Unfortunately, the shelter was not thriving either economically or environmentally. Over all, staff members feel as though residents are generally satisfied with the facility and most complaints from both staff members and residents would mainly include concern for: temperature regulation, accessibility, plumbing issues and the leaking roof.

4.5. *Resident Questionnaire*

A resident survey questionnaire was given to residents and administered in a group setting. Each question was formulated to gain insight into: resident perceptions of women's shelter's current facility, resident time spent at the shelter and some of the habits that residents implement while using the facility. The average resident at the women's shelter was between 44-48 years old with the most residents falling in the 54-58 years old category. The majority of the residents at the women's shelter had only been a resident for three months or less. According to survey responses, the average resident lived at the shelter for 3-5 months. Residents ranked the facility from 1 to 5 with one being very poor and 5 being very good. The survey responses revealed an average resident satisfaction rating of 4.2.

5. Conclusion

This case of adaptive reuse suggests that the key areas of concern for this facility should be: roofing, plumbing, HVAC equipment, community environment, end-user involvement, insulation, and the condition of exterior windows and doors. The building could better utilize the current layout as well as provide education to residents concerning utility cost savings by limiting use of fans and turning off unnecessary lighting. This facility did not serve as an optimal sustainable solution for the program. Because of the lack of efficiency, the shelter suffered financially with vast increases in gas during the cooler months and significant utilization of electric energy during hotter months. Until major changes are implemented, the shelter leadership will continue to sink unnecessary money into building repairs that do not directly aid in the long-term needs of the shelter.

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The Role of Emotional Intelligence in Managing Construction Projects

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Abstract

The success of any construction project is dependent on a range of factors. An often overlooked aspect is the role of emotional intelligence (EI) in ensuring the sustainability of a firm and promoting success and excellence. However, limited research has been conducted regarding the status and role of EI within the construction industry.
A literature survey pertaining to the role of EI in managing construction projects informed the development of an interview protocol, which was used to interview representatives of construction firms that are members of the East Cape Master Builders Association (ECMBA).
The salient findings include: most construction firms do not implement stress management strategies during the execution of construction projects; supervisors and workers do not necessarily develop negative attitudes on construction projects due to management's poor intrapersonal skills, however employees believe that EI is important and management need to be emotionally intelligent to be successful in construction; short-comings between levels of management exist during the execution of construction projects due to differences in opinions and personalities, and management encounter unforeseen problems and changes during the construction process and contain little knowledge of the improvements which can be made within the firm to adapt to changes. The EI competencies in the form of self-awareness, self-management, social awareness, and relationship management are important in terms of the managing of construction, and thus managers need to be emotionally intelligent, and for that matter employees too.
Conclusions include: the level of EI in construction is not ideal; the construction industry is stressful; there is a need to 'target' and manage stress, and there are underlying or root causes of stress.
Recommendations include: tertiary construction management programmes and construction firms should focus on the development of EI; communication should be promoted and forums directed towards promoting teamwork should be arranged; construction firms should develop stress management strategies and implement related programmes in order to help management and employees deal with stress.

Keywords: Construction, Emotional Intelligence, Performance

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1. Introduction

EI is defined as "the ability to perceive accurately, appraise, and express emotion; the ability to access and / or generate feelings when they facilitate thought; the ability to understand emotion and emotional knowledge; and the ability to regulate emotions." [1] The construct of EI is a vastly significant and dynamic quality recognised in employees who produce results, generate transformational change, and lead the firm as the motivating and inspiring force.

A number of factors influence the successful undertaking of people's private and working lives [2]. In the business world, people are more often than not viewed as the greatest asset to organisations. This statement highlights that human capital fulfilling different functions within an organisation has a far greater impact than tools and technology alone. Emotionally intelligence competencies go hand in hand with cognitive skills, where top performers encompass both. The absence of EI competencies can hinder the intellectual and technical proficiencies a person may possess and therefore EI is of greater importance on complex construction projects. In saying that, irrational and out-of-control emotions can make smart people 'stupid' and ultimately forfeit the success of a project [3].

Cherniss and Goleman [4] identified four domains of emotional intelligence namely: self-awareness; social awareness; self-Management, and relationship management. The importance of each area and their role in managing construction projects is the purpose of the research reported on in an endeavour to contribute to improving project performance and employee job satisfaction.

The objective of this paper is to report on a study that explored the perceptions of contractors regarding the use of goals / targets to improve H&S performance in South African construction. The research reported on explored ‘How important are the following actions / beliefs / interventions / practices / states in terms of achieving zero accidents, injuries, fatalities, and disease in construction', and 'to what extent do you disagree / agree with statements relative to construction H&S'.

2. Review of the Literature

2.1. *Emotional Intelligence Competencies*

To be emotionally intelligent means to understand and be aware of personal emotions and others. Given that management entails working through people, managers need to ‘manage’ the aforementioned effectively. Ultimately, it is the ability to express oneself in a group or to an individual in a non-destructive manner and to successfully facilitate personal, change, and problems, while being conscious of one’s behaviour as stated by Bar-On, Maree and Elias [4]. A number of schools use various models to elucidate EI as a contributing factor to continuous organisational success, outstanding leadership, and job satisfaction. Cherniss and Goleman [4] identified a framework of emotional competencies comprising twenty competencies nesting in four dimensions of emotional intelligence namely self-awareness, social awareness, self-management, and relationship management as presented in Figure 1.

Figure 1. A framework of Emotional Competencies.

	Self (Personal Competencies)	**Other (Social competencies)**
	Self-Awareness	**Social Awareness**
Recognition	Emotional self-awareness Accurate self-assessment Self-confidence	Empathy Service orientation Organisational awareness
	Self-Management	**Relationship Management**
Regulation	Emotional self-control Trustworthiness Conscientiousness Adaptability Achievement drive Initiative	Developing others Influence Communication Conflict management Visionary leadership Catalysing change Building bonds Teamwork, and collaboration

Extracted from Cherniss & Goleman [4]

The framework consists of personal (perceiving and managing one’s own emotions) and social competencies (perceiving and managing emotions in others):

Self-awareness: one's ability to recognise one's own feelings and emotions; the affect positive or negative emotions might have on one's ability to perform effectively and assessing one's strengths and limitations;
Self-management: this involves the ability to choose how one thinks, feels and acts; including controlling one's impulses and reactions to varying situations;
Social awareness: one's ability to recognise others feelings and emotions; showing empathy towards others; as well as understanding situations impartially and unassumingly, and
Relationship management: this implies developing others needs and skills; facilitating an environment for open communication and teamwork and identifying conflict resolution strategies to allow for fair negotiation and discussion.

2.2. *Emotional Intelligence in the Construction Industry*

EI, which is a crucial soft skill, is reported to have many benefits, yet it remains largely unexplored in construction project management [5]. The construction industry is conventionally perceived as being slow to implement new management techniques, in particular, the area of human resources. EI has proven to forecast the success of construction projects and improve project performance even though it is a relatively new approach in the industry [5]. Human factors are the driving force of any organisation and the successful execution of construction projects is largely dependent on the EI competencies of the project team and subordinates. Research determined that EI, when translated into practical competencies, are twice as important as IQ in contributing to outstanding and operational project performance [3]. It is thus clear that EI is a very important component of effective construction project completion in terms of open communication, delegation, proactive behaviour and conflict resolution [5]. The aforementioned is underscored by Love, Edwards and Wood [6], the most challenging or demanding aspect of construction projects are the interpersonal and relational aspects of the construction team's role. A number of EI skills and competencies are fundamental to construction managers, supervisors and workers as they interact with a variety of individuals at various levels such as clients, consultants, subcontractors and suppliers on a regular basis [6].

2.3. *Applying EI competencies to construction management*

Construction projects are generally people intensive. This can result in conflict occurring and high levels of stress. Negative attitudes develop due to poor intrapersonal skills as well as the mental well-being of role players being compromised. In order to cope with the negative emotions and unforeseen problems experienced on the job, which inevitably affect project performance, construction teams need a better understanding of and EI competencies in the form of knowledge and skills. "Leadership greatly impacts a number of aspects of organizational effectiveness, which includes production quality, efficiency, flexibility, satisfaction, competitiveness and development." (Chinowsky and Songer, 2011: 11). Nearly 90 percent of outstanding leader's qualities comprise of EI, which separates a good leader from a mediocre leader. Furthermore, teamwork is an important factor within the construction industry due to the increase in collaboration and group performance. Given the confirmed link between high performing firms within the construction industry and EI managers should strive to promote team efficiency and success through EI proficiencies [7].

Given that employees tend to seek support and empathy from their managers, managers have the potential to influence their employee's emotions and attitudes, and therefore they should focus on promoting enthusiasm and positivity and thereby enhanced performance, as opposed to negativity and anxiety, and consequent poor performance. [8].

3. Research

3.1. *Research method*

The targeted population included all contractors listed on the ECMBA list within the Nelson Mandela Bay Metropolitan. The sample size included eight purposefully selected contracting firms within Port Elizabeth. One employee from each firm was identifed based on experience and availability, and contacted telephonically to determine his willingness to be interviewed.

In terms of qualifications 50% of respondents were qualified with a diploma, 37.5% with an Honours degree, 25% with a Bachelors degree, and 12.5% with a BTech degree. In terms of occupations, 75% were senior site agents, and 25% were contracts managers. Nearly the majority of respondents (62.5%) had worked ≥ 20 years in construction, and 12.5% for each of > 0 ≤ 5 years, > 5 ≤ 10 years, and > 10 ≤ 15 years. In terms of age 50.0% of the respondents were > 35 ≤ 45, 25.0% were > 25 ≤ 35 years, and 12.5% each of > 55 ≤ 65 years, and 12.5% > 65 years. 100% of the interviewees were male. In summary, the interviewees had immense experience, 75% having more than 15 years of managerial experience in construction, 83.3% of which have more than 20 years of managerial experience in construction. All eight respondents are male and obtain a degree or diploma from a tertiary educational institution. The aforementioned indicates that the interviewees possess sufficient experience and knowledge pertaining to the construction industry and the data obtained from them is relaiable and relevant.

3.2. *Research findings*

Interviewees were asked if they knew what EI is. 75% of the respondents knew what EI is, while 25% of the respondents had no idea what EI is. The respondents who were familiar with the term where asked to describe their understanding of EI. The responses received included:

Interviewee 1: “EI is all the soft, fluffy stuff.”

Interviewee 3: “Happy place. It’s emote language. It is to have the ability to know when to have which emotions, so that you can defuse any situation.”

Interviewee 4: “EI is how you deal with the softer side of construction. How you handle different people in different stages and different phases. It is basically working with different personalities.”

Interviewee 5: “Soft soaping someone and making them feel good. The people working for us are currently very negative because of the current economic conditions we are experiencing. Therefore, we need to motivate them and encourage them to work hard, emphasise teamwork and acknowledge the work they produce.”

Interviewee 6: “If you start to scream and shout, your intelligence comes down.”

Interviewee 7: “It is how you handle situations mostly. If you are an emotionally strong person, you will be able to think situations through rationally. If you are not emotionally strong, you tend to lose it and get angry and you don’t think things through clearly.”

The abovementioned interviewees were then asked if they think EI is important as well as why they thought EI is important, all of which agreed that EI is important. Two interviewees stated that one can no longer be a ‘stick beater’ as one used to be due to the changed conditions of the industry.

37.5% of the interviewees stated that their managers lack empathy. 37.5% concluded that the pressure of construction limits management’s capacity to empathise with their employees. A further 37.5% concluded that to a certain extent, management does lack empathy depending on the type of project being executed, the company you are employed by and the people you are dealing with. Only one of the interviewees who agreed that management lacks empathy said that he has developed a negative attitude as a result. Another interviewee mentioned that when he was younger he would have develop a negative attitude but he no longer does because he is confident in his working ability.

A further interviewee said that management’s lacking of empathy does not affect his performance, but it affects him as a person and those around you. One interviewee mentioned the following: “It does affect your performance. It depends on what type of person you are. You need to talk to those superiors and express your dissatisfaction and ask how we can fix the situation. I think a lot of employees don’t do that because they are not comfortable approaching their superiors.”

75% of the interviewees perceive that their manager / executive acknowledges them as individuals. One interviewee said that his manager does not acknowledge him as an individual. His comment was: “I believe I am just a money making machine for him. He only cares about his wife and his dogs.” The interviewees were asked to explain why they believe that their manager / executive acknowledges them as individuals. One interviewee said that it comes back to teamwork. He said that within their firm, they have the philosophy that it takes both upwards and downwards to make a success of a business in terms of the firm’s hierarchy. He relies on the success of the people working for him to make him a success and his manager allows him to be successful. He also mentioned that it is not necessarily a common thing within the construction industry, but within his firm, everyone tries to provide praise where it’s due. Two interviewees agreed that their managers have given them managerial responsibilities, which proves that they are acknowledged in terms of their experience and trustworthiness. 75% of interviewees perceive that their manager / executive acknowledges the work they deliver. One (12.5%) interviewee said that his manager does not acknowledge the work that he delivers, because his manager is only interested in seeing the money come in. His manager never visits his projects, yet he always finds fault. When projects are successful, his manager never seems to notice. 37.5% of interviewees stated that the reason they perceive the work they deliver is acknowledged and appreciated is because of their position they hold in the firm and their responsibilities.

All interviewees were in consensus that there is a need for one’s manager to be emotionally intelligent. The interviewees were then asked to explain why there is a need for one’s manager to be emotionally intelligent. All agreed that construction is people intensive, and people are emotional. EI often distinguishes a good manager from a bad manager.

The interviewees were asked if they experienced stress, of which 75% said ‘Yes’. The other 25% said that they used to experience a great deal of stress, but since both developed stress-related illnesses in their earlier years, they no longer experience stress due to the medication they take for their health. In terms of how frequently they experience stress, 62.5% stated that they experience stress on a daily basis, and one (12.5%) said that he experiences stress three times a week. The interviewees were then asked to identify the main causes of stress. All the interviewees identified time, money, and people as being the major causes of stress. Comments include: “The activities and people on site. Construction is easy, it is people that make it difficult.” and “Daily pressure. Time constraints. You have to do a task, which in any other given area would take you about two or three days to complete, you have to complete that task in one day in construction. Your superiors are unrealistic in the targets.” 62.5% of interviewees stated that stress management strategies do not exist within the firm, while the other 37.5% were able to identify some form of stress management programme / strategy supported by their firm, in order to help employees deal with stress. Comments from those interviewees that responded in the negative include: “In the bigger companies, they have courses. I used to be extremely aggressive in my younger years because of stress. When I worked for the bigger companies, they would put me on courses and help me to deal with stress and that helped me a lot. With the smaller companies, there is no help.” All three interviewees that responded in the affirmative stated that their firms either make use of either a psychologist or a counsellor, who is available and can be contacted to discuss any problems or issues of stress experienced. The same three interviewees were asked if they believe that the strategies are effective. One respondent said that he does not need to comment regarding the strategies which the firm provides in order to deal with stress. Another interviewee stated that the strategies can help for a period, but if nothing changes within the firm then they are not effective. The third interviewee said that the strategies implemented within the firm definitely do help. Furthermore, the five (62.5%) of interviewees who stated that their firms do not have stress management strategies within their firms to help them deal with stress all agreed that it is necessary to implement stress management strategies within the firm to encourage positivity and collaboration. In terms of interviewees’ coping mechanisms adopted to deal with stress, all (100%) interviewees agreed that spending time with their families and incorporating one or two hobbies in their private time helps to cope with stress. Two interviewees had experienced heart attacks at a young age and both agreed that their heart attacks were likely to have been related to their highly stressful occupations. The majority of the interviewees acknowledged that one’s health and well-being is compromised when one is under a great deal of stress and is thus a consequence of stress. Only one interviewee stated that stress could reap negativity. Three (37.5%) of the interviewees noted that stress can put strain on one’s family life and on one’s relationships within and outside the firm, while two (25%) interviewees highlighted that they in fact thrive on stress and become more productive as a result. The interviewees were asked to identify ways to reduce stress. Some of the responses include:

“Reducing stress is linked to the way in which you cope with it. Construction is not a production line where you go to work and know exactly what is going to happen in the day. You can do your planning as best as possible, but there will always be curved balls and it is how you deal with those curved balls, which can reduce stress.”

If there were better structures in place within the firm, then a lot of stress could be reduced, and the shortage of skilled artisans in South Africa creates stress. If there were better quality labourers with the right knowledge and skill, a lot of stress could be reduced;

More assistance and recognition from top management could reduce stress, and

Reducing stress comes down to better planning, working with decent people, sharing responsibilities with your peers, and planning meetings on a daily basis.

87.5% of interviewees do not experience difficulty expressing their opinion in a group or to an individual. The remaining interviewee said ‘Yes’ and ‘No’. Of those interviewees who do not experience difficulty expressing their opinion in a group or to an individual, two interviewees stated that they make use of their experience and knowledge when being assertive, and a further two stated that the style they apply to be assertive and express themselves will depend on the situation, circumstances, or people they are dealing with. The interviewee that responded ‘Yes’ and ‘No’ stated that the circumstances and the group or individual with whom he is communicating with will determine whether he will be able to act assertively. He struggles to act assertively with people he is not comfortable with or people who do not listen to him and thus he struggles to reason with them and get his point across. The same interviewee stated that in terms of emotions, he feels disappointed and a bit angry because of the difficulty experienced when expressing his opinion.

In terms of relationships with their superior, 62.5% of interviewees perceive that they are treated fairly and with respect by their manager / executive. Two (25%) clearly stated that their relationship with their superiors is non-existent. The interviewees were then asked to describe their relationship with their manager / executive. 50% of the interviewees were of the opinion that their relationship with their manager or boss is very good. Other interviewees responded as follows: “Non-existent.”; “We have no relationship at all. We work together and that is it.", and "Where there are short-comings in our relationship, I think it is because he is under a lot of pressure. It is difficult for him to have a good relationship with me because he has his own stress and pressure to deal with and thus does not have the time."

In terms of conflict 37.5% of interviewees identified money and time as being the major cause of conflict or disagreement arising between themselves and upper management. A further 37.5% noted that conflict arises between themselves and their superiors because their superiors are not involved with the daily on-site operations, yet their superiors interfere with their planning and criticise their work. Only one interviewee mentioned that he develops a negative attitude because of conflict arising between him and his superior. He also said that poor relationships are formed and you lose trust.

The interviewees were asked to describe their 'relationship' with themselves. The majority of the respondents stated that they have a good relationship with themselves. One respondent mentioned that he was his biggest critic and he generally puts a lot of pressure on himself.

In terms of teamwork, the majority (87.5%) of the interviewees stated that they give higher priority to the group's goals than their personal goals. One interviewee stated that he maintains a balance between work and personal goals. Two (25%) interviewees stated that there is no 'I' in 'team'.

4. Conclusions and Recommendations

The EI competencies in the form of self-awareness, self-management, social awareness, and relationship management are important in terms of the managing of construction, and thus managers need to be emotionally intelligent, and for that matter employees too.

However, relative to the interviewees, given the prevailing understanding of EI, the degree of empathy experienced, the nature of relationships experienced with superiors, the degree of recognition afforded, the occurrence of conflict, the degree of stress experienced, and the level of confidence, it can be concluded that the level of EI in construction is not ideal.

Given the degree of stress experienced it can be concluded that the construction industry is stressful, that there is a need to 'target' and manage stress, and although EI has major potential to contribute to mitigating stress, there are underlying or root causes of stress such as volume of work relative to project duration. , should be addressed at 'source'.

Tertiary construction management programmes and construction firms should focus on the development of EI. Communication should be promoted and forums directed towards promoting teamwork should be arranged. Construction firms should develop stress management strategies and implement related programmes in order to help management and employees deal with stress. However, the underlying or root causes of stress such as volume of work relative to project duration, should be addressed at 'source'.

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Towards Zero Fatalities, Injuries, and Disease in Construction

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Abstract

This study explores the 'holy grail' of health and safety (H&S) - zero fatalities, injuries, and disease! Although, the logic of pursuing such a goal is obvious there are many 'non-believers' in the sense that they do not believe it is achievable. However, the literature indicates that such a goal is an integral part of H&S culture, and is complementary to the vision of fatality, injury, and disease free construction. Furthermore, it is the only 'transparent' goal.
A study conducted among a convenience sample of ‘better practice H&S’ general contractors determined that client contributions, ‘designing for construction H&S’, integration of design and construction, appropriate procurement, contractor planning, risk assessment, an optimum interface between H&S, quality, and the environment including the respective management systems, H&S education and training for all stakeholders, core competencies, and consciousness and mindfulness, will contribute to the realisation of ‘zero’.
Conclusions and recommendations include the achieving of ‘zero’ requires a multi-stakeholder effort on a project basis, including a partnering type process, and synergy between groups of actions / beliefs / interventions / practices / states i.e. the requisite ‘cocktail’ of factors must be in place and to an optimum extent.

Keywords: Construction, Fatalities, Health and Safety (H&S), Injuries, Zero

1. Introduction

Industrial safety research defines a 'safe' work site as one where injuries and fatalities constitute 'zero' sum [1]. According to Wilkins [2], in construction, contractors have adopted such targets in order to keep their workers safe and abide with regulations in a compliance-based H&S environment.

However, case studies indicate that zero targets are goals that are difficult to attain. A New Zealand hazardous industrial plant study assessed the effects of such a target and noted that even though a firm adopted and focused on a 'zero target' for decades, attainment has been vague for various reasons that manifest through hazard misunderstandings and misinterpretations [1]. Although the firm has recorded an astonishing reduction in lost time injuries (LTIs) owing to the use of the target, minor incidents have deprived the firm of success.

The Construction Industry Development Board (cidb) [3] ‘Construction Health & Safety Status & Recommendations’ report regarding H&S in South African construction records that Department of Labour inspections determined that 52.5% of contractors were non-compliant, and the disabling injury incidence rate (DIIR) is 0.98 i.e. 0.98 disabling injuries per 100 workers, and a fatality rate of 25.5 per 100 000 workers. Clearly, the goal of zero fatalities, injuries, and disease is not ‘current reality’ in South African construction, and therefore interventions beyond compliance-based H&S are required. However, ‘current reality’ should not be accepted as a *fait accompli*, and therefore
this paper is premised on the need to realise continuous improvement in construction H&S, and the goal of ‘zero’ and the role thereof should be explored. The objective of this paper is to report on a study that explored the perceptions of contractors regarding the use of goals / targets to improve H&S performance in South African construction. The research reported on explored ‘How important are the following actions / beliefs / interventions / practices / states in terms of achieving zero accidents, injuries, fatalities, and disease in construction', and 'to what extent do you disagree / agree with statements relative to construction H&S'.

2. Review of the Literature

2.1. *The zero target debate*

Zwetsloot et al. [4] argue that while the use of goals has been advocated because of improved H&S performance, a range of challenges exist in various contexts where such goals are supposed to eliminate hazards and accidents. Socio-technical work environment and negative effects of such goals constitute reported challenges.

In terms of the socio-technical work environment, multiple incident and accident causations are a major hurdle in an industrial setting similar to the one on a construction project. The British Petroleum (BP) Deepwater Horizon accident in 2010 in an industry that appears to have superior H&S programmes constitutes an example. In essence the report concluded that a complex and interlinked series of mechanical failures, human judgements, engineering design, operational implementation, and team interfaces collectively triggered the initiation and escalation of the accident i.e. no single action or inaction caused the accident [5]. The BP accident occurred in an industry where large organisations are committed to goals in the form of 'zero harm', and 'zero accident vision (ZAV)', to mention a few. Such goals are often seen in company reports, policies, H&S manuals, and even websites where construction companies in the United Kingdom (UK) (and elsewhere, including South Africa) also indicate their commitment to higher standards of H&S [6]. Dekker et al.[7] note that goals may not necessarily mean a commitment to 'no accident' at all levels of severity and in fact, goals may conceal severe accidents and imply that near-misses and minor accidents are inevitable and required for making learning happen from everyday work and failures in a complex socio-technical system. Excessive measurement, erudite data computations, and high bureaucratic systems backed up by regulations from compliance-based safety regimes are some of the reported negative effects of setting goals [8; 9). Although bureaucratic accountability within organisations has manifested in gains in the form of a reduction in harm, Dekker [8] reports that it is generating concerns that run counter to the original goals. Such effects include, *inter alia*, the inability to predict unexpected events, the so called 'number games', and the creation of new H&S problems. A Finnish construction study in turn determined that there is a strong negative correlation between incident rate and fatalities, which implies that the fewer incidents that are reported, the higher the fatality rate [10].

The practical realities of 'zero targets' in the United Kingdom construction industry were investigated by Sharratt [11]), and based on the information collected from five large contractors operating 'zero target' H&S programmes, concluded that 'zero' was viewed as a philosophy and a target with different interpretations in practice.

2.2. *The role of zero targets*

Yi Man Li and Wah Poon [12] state that accident rates in Hong Kong have reduced significantly over the past few years. Many of the systems and approaches are locally developed, with large numbers of systems and technology being imported. Of significance is the use of the Total Quality Management (TQM) based H&S Management Systems (H&SMS), where the goal is zero accidents. H&S is built into the work as it commences, H&S conformance is required; all employees are required to be involved, and a continuous improvement approach accepted as part of the TQM systems approach, based on the theory of TQM based SMS, namely that all accidents are avoidable [12].

2.3. *Are zero targets achievable?*

A United Kingdom (UK) construction company, namely Frank Haslam Milan (FHm), which already had an above average H&S record in 2002, achieved its target of a zero accident rate through a training and awareness initiative involving its employees [13]. The Human Resources Manager, Irene Liddle, states that they realised they had to raise H&S awareness throughout the company and ensure that everyone, from director to subcontractor, was highly competent in general H&S issues. Furthermore, she states that employees are increasingly contributing their own ideas to improve H&S, as opposed to simply following management's H&S instructions, which amplifies the value of worker participation in H&S [13].

According to Shiplee, Waterman, Furniss, Seal and Jones [14], the workforce on the Olympic Park site in east London peaked at 12 000 and a total of 30 000 people will have worked on the project through its lifetime. Through careful planning, implementation of strategies with a proven track record and clear leadership, the Olympic Delivery Authority (ODA) managed to achieve an accident frequency rate comparable to the average for all British employment, significantly better than the construction sector, and zero fatalities. There were five key elements to the H&S programme, as follows. Safety – clear policies, risk assessments, method statements, common standards, visual standards, daily activity briefings. Health – pre-employment medical checks, prevention programme, assessment and control, health surveillance, training, emergency response. Well-being – advice, well man / woman clinics, good food strategy, campaigns, sexual health clinics, partnerships. Competence – induction, training, supervisor academy, briefings, apprenticeships, checks and records. Culture – leadership, action plans, near-miss reporting, communications, reward and recognition, climate tool. The aforementioned, in particular the elements of health and well-being, reflect 'respect for people'.

Current reality in the form of accidents is frequently referred to as a counter to the 'zero target' initiative. Schwartz [15] maintains unsuccessful people suffer from a mind deadening thought disease called 'excusitis'. Every failure has the disease in its advanced form. However, the more successful the individual, the less inclined he / she is to make excuses. Schwartz also cites a traffic engineer's contention that there is no such a thing as a true accident. An accident is a result of human or mechanical failure, or a combination of both – nothing happens without a cause.

3. Research

3.1. *Research method*

An exploratory survey was conducted to determine the importance of actions / beliefs / interventions / practices / states in terms of achieving zero accidents, injuries, fatalities, and disease in construction and perceptions related there. A convenience sample consisting of twelve general contractors was used for the survey based upon their commitment to H&S and hence willingness to facilitate the survey. The managing director or H&S coordinator in the respective organisations circulated the questionnaire and returned the completed questionnaires to the lead researcher / author. The questionnaire consisted of two close-ended five-point Likert scale type questions, and one open ended question. At the end of the survey period, 92 responses were received, which were included in the analysis of the data.

In terms of demographic information, the mean age of respondents is 39.8 years, the mean years worked for current employer is 5.5 years and in construction is 14.5 years, and 91.1% are male 8.9% are female. A total of 46 qualifications and 31 occupations were recorded. 64.8% of respondents were qualified with either a diploma or a degree. Contracts manager (17.9%) and H&S Officer (10.9%) predominated among occupations.

3.2. *Research findings*

Respondents were requested to indicate the importance of thirty-eight actions / beliefs / interventions / practices / states in terms of achieving zero accidents, injuries, fatalities, and disease in construction relative to a five point scale of 1 (least) to 5 (very). Mean scores (MSs) between 1.00 and 5.00, based upon the percentage responses, were computed to produce a measure of central tendency and enable ranking of the actions / beliefs / interventions / practices / states. It is notable that all the MSs are > 3.00, which indicates that the actions / beliefs / interventions / practices / states are very as opposed to least important. Furthermore, 27 / 38 (71.1%) MSs are $> 4.20 \leq 5.00$, which indicates that the importance is between more than important to very / very important. The remaining 11 / 38 (28.9%) MSs are $> 3.40 \leq 4.20$, which indicates that the importance is between important to more than important / more than important. Due to the need for paucity, only the first third (13 / 38) of the actions / beliefs / interventions / practices / states have been presented in Table 1 and discussed hereafter.

People are our most important resource is ranked first, followed by zero harm, which should be the goal if people are the most important resource. A goal of 'Zero harm' is also accompanied by a goal of 'Zero accidents' ranked fourth, and a goal of 'Zero incidents' ranked fifth. A mission of 'continuous improvement' is ranked third, which is imperative in terms of the journey towards 'zero'. Consciousness and mindfulness ranked sixth is critical as the former implies cognising in terms of actually observing the environment and mindfulness in terms of realising the implications of the status quo or actions or omissions. H&S management system, and respect for people are ranked seventh and eighth respectively. The former provides the framework for H&S in an organisation, and the latter is necessary if 'people are our most important resource'. Design and construction hazard identification and risk assessments (HIRAs) are ranked ninth and tenth respectively and highlight the role of risk assessments in achieving 'zero'. Furthermore, in the case of the former it is the highest ranked designer action. A vision of a 'Fatality, injury, and disease-free work place' is ranked eleventh, and influences the achievement of 'zero'. Core competencies is ranked twelfth, which influence the achievement of 'zero'. Conformance to requirements, ranked thirteenth, relates to quality, and is a prerequisite for the achievement of 'zero'.

Table 1: Importance of actions / beliefs / interventions / practices / states in terms of achieving zero accidents, injuries, fatalities, and disease in construction

Action / Belief / Intervention / Practice / State	U	Least. ………………………Very					MS	Rank
		1	2	3	4	5		
People are our most important resource	0.0	0.0	1.1	4.3	8.7	85.9	4.79	1
A goal of ‘Zero harm’	0.0	0.0	0.0	3.3	20.7	76.1	4.73	2
A mission of ‘continuous improvement’	0.0	0.0	0.0	4.4	19.8	75.8	4.71	3
A goal of ‘Zero accidents’	0.0	0.0	1.1	3.3	25.0	70.7	4.65	4
A goal of ‘Zero incidents’	0.0	1.1	1.1	3.3	21.7	72.8	4.64	5
Consciousness and mindfulness	1.1	0.0	0.0	6.6	27.5	64.8	4.59	6
H&S management system	0.0	0.0	0.0	3.3	35.2	61.5	4.58	7
Respect for people	0.0	0.0	1.1	8.8	20.9	69.2	4.58	8
Design hazard identification and risk assessments	0.0	0.0	0.0	4.3	34.8	60.9	4.57	9
Construction hazard identification and risk assessments	1.1	0.0	1.1	3.3	33.7	60.9	4.56	10
A vision of a ‘Fatality, injury, and disease-free work place’	0.0	2.2	0.0	5.4	26.1	66.3	4.54	11
Core competencies e.g. values, aptitude, and integrity	1.1	0.0	2.2	7.7	29.7	59.3	4.48	12
Conformance to requirements	0.0	1.1	0.0	7.6	34.8	56.5	4.46	13

Table 2 indicates the extent to which respondents concur with statements relative to construction H&S on a scale of strongly disagree to strongly agree, and MSs between 1.00 and 5.00. It is notable that 18 of the statements have MSs > 3.00, which indicates that in general, the respondents agreed with the statements. Two untrue statements, namely ‘Accidents are unplanned events’ and ‘Construction is inherently dangerous’ attracted mostly agreement. The only ‘true’ statement that attracted mostly disagreement is ‘accidents occur by default i.e. planned’ i.e. it should have attracted mostly agreement as when accidents are reviewed, invariably acts or omissions resulted therein, thus they are planned by default as they could have been prevented. Two ‘untrue’ statements, namely ‘accidents are part of the job’ and ‘accidents are project requirements (especially on complex projects)’ attracted mostly disagreement, which they should have. The MSs of the first five statements tabled are > 4.20 ≤ 5.00, which indicates that the concurrence is between agree to strongly agree / strongly agree. ‘H&S does not happen by chance, it must be planned’ achieved the highest MS, namely 4.53. This is followed by ‘The goal of ‘Zero fatalities, injuries, and disease’ is an integral part of H&S culture’, which amplifies the importance of a ‘zero’ agenda. This in turn is followed by ‘The goal of ‘zero fatalities, injuries, and disease’ complements the vision of ‘A fatality, injury, and disease free workplace’, which further amplifies the importance of a ‘zero’ agenda, and its role. The ‘zero’ agenda is further motivated by the MS (4.36) of ‘The vision should be ‘A fatality, injury, and disease free workplace’. A notable finding is the MS of ‘Zero fatalities is achievable’ – notable in terms of the concurrence that such a goal is actually achievable.

The MSs of the next thirteen statements are > 3.40 ≤ 4.20, which indicates that the concurrence is between neutral to agree / agree. The goal of ‘zero fatalities, injuries, and disease is a pre-requisite for optimum H&S performance’ amplifies the role of such a goal. Firstly, in terms of zero being the measure of optimum, and secondly, it being a motivator as it rallies people around the goal. ‘Zero accidents is achievable’ and ‘Zero injuries is achievable’ underscore ‘Zero fatalities is achievable’ addressed above. However, they are perceived to be ‘less achievable’ than zero fatalities. ‘Accidents are unplanned events’ is as per international definitions, however, current perspectives are that they in fact are not, as if actions or omissions, which are invariably ‘knowingly’ taken or occur, then in fact they are planned, hence ‘Accidents occur by default i.e. planned’ which is discussed hereafter. The aforementioned argument is supported by Schwartz (1995) who cites a traffic engineer’s contention that there is no such a thing as a true accident. An accident is a result of human or mechanical failure, or a combination of both – nothing happens without a cause. ‘Hazards and associated risk can be quantified’ is acknowledged in the literature and hazard identification and risk assessment (HIRA) is required in terms of H&S legislation and regulations worldwide. ‘Excusitis (the proffering of excuses) marginalises H&S’ is a contention expressed by Schwartz (1995). ‘Zero incidents is achievable’, ‘Zero fatalities, injuries, and disease is achievable’, ‘Zero disease is achievable’, and ‘Zero deviations is achievable’ further underscore the ‘zero agenda’. However, they are perceived to be ‘less achievable’ than zero fatalities, zero accidents, and zero injuries. ‘The focus on cost, quality, and time marginalises H&S’ is widely accepted worldwide. However, the concurrence relative to ‘Construction is inherently dangerous’ is notable as in fact it is not the case as firstly, it implies that nothing can be done to mitigate ‘danger’ i.e. hazards, which is not the case. Secondly, strategies, systems, procedures, and protocol can at least mitigate, and in cases eliminate hazards and risk. ‘H&S is a value not a priority’ is an important contention as priorities change, hence H&S should be a value.

Only two statements’ MSs > 1.80 ≤ 2.60 (strongly disagree to disagree / disagree), namely ‘Accidents occur by default i.e. planned’ and ‘Accidents are part of the job’. As discussed above, the former is untrue as when accidents are reviewed, invariably acts or omissions resulted therein, thus they are planned by default as they could have been prevented. Accidents are certainly not part of the job, as construction is not inherently dangerous.

‘Accidents are project requirements (especially on complex projects)’ achieved a MS ≥ 100 ≤ 1.80 (strongly disagree to disagree). This may sound obvious, however it is notable that there was not universal ‘strongly disagree’.

Table 2. Extent to which respondents concur with statements relative to construction H&S.

Statement	Response (%)						MS
	Unsure	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
H&S does not happen by chance, it must be planned	1.1	2.2	0.0	1.1	35.2	60.4	4.53
The goal of ‘Zero fatalities, injuries, and disease’ is an integral part of H&S culture	0.0	0.0	0.0	3.3	48.9	47.8	4.44
The goal of ‘zero fatalities, injuries, and disease’ complements the vision of ‘A fatality, injury, and disease free workplace’	2.2	0.0	0.0	1.1	57.1	39.6	4.39
The vision should be ‘A fatality, injury, and disease free workplace’	0.0	0.0	2.2	3.3	50.5	44.0	4.36
‘Zero fatalities’ is achievable	0.0	0.0	5.6	1.1	53.3	40.0	4.28
The goal of ‘Zero fatalities, injuries, and disease’ is a pre-requisite for optimum H&S performance	0.0	0.0	2.2	10.0	53.3	34.4	4.20
‘Zero accidents’ is achievable	0.0	0.0	11.1	4.4	56.7	27.8	4.01
‘Zero injuries’ is achievable	0.0	0.0	10.0	6.7	57.8	25.6	3.99
Accidents are unplanned events	0.0	5.5	6.6	5.5	50.5	31.9	3.97
Hazards and associated risk can be quantified	0.0	3.3	4.4	12.1	57.1	23.1	3.92
‘Excusitis’ (the proffering of excuses) marginalises H&S	8.0	3.4	8.0	6.8	52.3	21.6	3.88
‘Zero incidents’ is achievable	0.0	1.1	12.2	6.7	60.0	20.0	3.86
Construction is inherently dangerous	0.0	4.4	12.2	11.1	44.4	27.8	3.79
‘Zero fatalities, injuries, and disease’ is achievable	0.0	1.1	13.2	17.6	47.3	20.9	3.74
‘Zero disease’ is achievable	0.0	1.1	17.0	13.6	46.6	21.6	3.70
The focus on cost, quality, and time marginalises H&S	1.1	3.4	16.9	9.0	50.6	19.1	3.66
‘Zero deviations’ is achievable	1.1	2.2	22.5	7.9	49.4	16.9	3.57
H&S is a value not a priority	2.2	16.9	13.5	7.9	24.7	34.8	3.48
Accidents occur by default i.e. planned	3.3	36.3	37.4	8.8	11.0	3.3	2.05
Accidents are part of the job	0.0	48.9	27.8	11.1	12.2	0.0	1.87
Accidents are project requirements (especially on complex projects)	0.0	59.3	27.5	6.6	3.3	3.3	1.64

4. Conclusions

A sound foundation in the form of ’people are the most important resource’ and ’respect for people’ must be provided for the ’zero target’ journey; journey as current reality manifests itself in the form of fatalities, injuries, and disease and therefore continuous improvement is necessary to achieve the vision and goal of ‘Zero fatalities, injuries, and disease’. The literature confirms the importance of TQM and that the goal is achievable. The empirical findings in turn indicate that the ’zero fatalities’ zero target is more achievable than the other targets. However, a multi-stakeholder effort is required. Therefore, at the very least, H&S must be a ’project value’ as opposed to a contractor responsibility’, and ideally a partnering approach which focuses the efforts of all project stakeholders on H&S should be adopted. Furthermore, hazard identication and risk assessment during design and construction, conformance to requirements, and conciousness and mindfulness are critical. Then, the issue of competencies, not solely surface competencies, but core competencies such as values, aptitude, and integrity are pre-requisites for maintaining focus on H&S, ensuring compliance, and realising of ’zero targets’. Finally, given that there are prerequisites there is clearly synergy between the various actions / beliefs / interventions / practices / states i.e. the requisite ‘cocktail’ of factors must be in place and to an optimum extent.

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Passive House Performance Standards and Climate Considerations

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Abstract

Optimizing energy performance of buildings requires a multi-disciplinary team approach to integrating architecture with the systems that condition the environment inside the building. The popularized passive house design criteria have provided a road map to achieving lower energy use in buildings for almost two decades in Germany and for nearly a decade in the United States. Passive House standards have been formally utilized and documented in certification of buildings and informs the design of low-energy buildings through the use of scientific analysis of weather and climate data along with solar exposure of the site to inform the building's site orientation, shape, and envelope level of insulation and glazing to drive requirements for energy and electricity lower in buildings. There has been criticism in the past however, that the standards for passive houses were developed without regard to extreme climate conditions outside of temperate climate typically found in Germany. In recent years, with a wide variety of climate zones represented in the United States, the Passive House Institute of the United States (PHIUS) formed a Technical Committee in conjunction with Department of Energy (DOE) to study climate zones in relation to the established standards and propose variations appropriate for those locations that are better suited for optimized energy performance. The acknowledgement and study of Passive House Standards and climate zone application by the PHIUS Technical Committee and the DOE is a step in the right direction for inspiring design teams and owners in other regions to pursue nearly net zero and net zero designs.

Keywords: Passive House, Energy Efficiency, Superinsulation, Building Envelope, Airtightness, Climate

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1. Introduction

Buildings in the United States account for almost 40% of energy consumption and 72% of electricity consumption, with the residential sector leading commercial sector in consumption [1]. After buildings are constructed and turned over for occupancy they are typically in operation and contribute to the national energy consumption rate for decades. With high consumption rates reported for buildings, responses to climate change, and increasing costs of natural resources, energy efficiency has become an industry focus following decades of varying levels of interest and attention toward improving our conservation of valuable natural resources.

Initial engineering design theories to achieve lower energy consumption first emerged in the 1970s as a reaction to the 1973 oil crisis. Over time, these design theories have been further developed and evolved with implementation and real world testing in construction driven by building regulations that support conservation of natural resources and promote use of renewable energy sources. Prior to the energy crisis, homes and buildings were designed and built with little concern for energy cost; single pane windows were common and insulation of walls and roof assemblies were considered adequate with R-13 and R-20 component values respectively ("R" represents thermal resistance of a building component). Through the advancement of building technology and passive house concepts implemented and proven, windows are now minimally double-pane rather than single pane; standard wall insulation is now a minimum of R-20 and roof insulation is R-32 [2].

Concepts of passive solar design were introduced to the public in the 1970s following the energy crisis as a response to the crippling economic affects this event had on the western world and its dependence on fuel consumption. Passive solar concepts scientifically informed building orientation and form optimization for energy efficiency of buildings by being responsive to the specific climate and site and controlling solar heat gain of the building. These design concepts were a first step towards energy optimization and were limited to architectural elements of a building. Ideas of increased insulation or "super insulation" of the envelope emerged later in the 1980s. Following the emergence of passive solar design and superinsulation was the development of Passivhaus standards formalized in Germany by Wolfgang Feist who formed the Passivhaus Institute in Darmstadt, Germany in 1996 with the goal of creating ultra-low energy buildings. In 2007 the German trained architect, Katrin Klingenberg advocated Passive House standards in the United States and is responsible for establishing the Passive House Institute of the United States (PHIUS) with standards resembling the licensed German Passivhaus standard [3].

While Passive House standards have been revered for their simplicity they have also been criticized for rigidity and limited application to buildings found in temperate, less extreme climates. It is acknowledged that the standards were created without much regard or study for application in extreme climate zones [4]. In recent years, with a wide variety of climate zones represented in the United States the Passive House Institute of the United States formed a Technical Committee in conjunction with Department of Energy to study climate zones in relation to the established standards and propose variations appropriate for those locations that are better suited for optimized energy performance [5].

2. Climate Specific Design for Energy Efficiency

2.1. *Passive House Standards by Climate Zone*

In late 2011, Passive House Institute of the United States (PHIUS) formed a Technical Committee to develop an adaptation of the standard and the committee introduced Climate-Specific Passive Building Standards for the United States Department of Energy (DOE) in March 2015 in an attempt to drive buildings closer to net zero utilizing passive measures. These are preferred measures that result in increased occupant comfort, durable construction, improved health and resiliency, and can be cost effective. To achieve net zero energy facilities it has been established that renewable energy systems are necessary to get there.

Passive design principles outlined in the previous section were first pioneered in North America following the oil crisis of the 1970s and later refined in the 1990s in Europe. The principles have been tested and proven to be generally effective in reducing heating and cooling loads on buildings significantly as compared to conventional construction. As a result, the Passivhaus system was developed in Germany with strict parameters shaped around the climate of the country rather than acknowledging diverse climate types found in other regions. When implementing Passivhaus standards as developed in Germany there were many cases where design decisions had negative results in thermal comfort and cost effectiveness for the end results. Therefore, the inclusion of these principles in building construction in the United States has been slow in adoption in many regions of the United States.

One of the main critiques of the German based Passivhaus standard's passive/conservation performance metric used as a guideline for developing the building envelope and systems for space conditioning criteria is not set up for responsiveness to a diverse climates and energy markets found across the United States. This standard was originally established for use in Germany, in a climate that has moderate heating and cooling requirements. Theoretically Passive House standards can be achieved in any climate zone however, attempting to do so in extreme climate conditions can be so prohibitively expensive that the costs to do so would not be justified over the life of the building[4]. These concerns along with the invested interest of encouraging designers and owners in all climate zones to work towards achieving near net zero results in buildings created this opportunity to study the standards and their cost effective application in the range of climate types found in the United States.

Since 2007, PHIUS has promoted the use of the European based energy metrics for buildings constructed in the U.S. and Canada with over 100 projects completed in various climates and meeting the criteria two main issues were identified: 1) Different cost structure implies a different economic optimum, and 2) Interaction or criteria and climate misled designers [5]. The first issue is related to the blanket standard building metric of 15kWh/m^2yr (4.75 kBtu/ft^2yr) annual heat demand that is derived from central Europe as there is a clear break point of cost-competitive economics however, in the U.S. there is not a clear cost-optimized metric for all climate zones and regions where it would be cost competitive to take costs out of heating and cooling systems to place in the envelope. The second issue is concerned with the relationship between degree-days and peak design temperature. These factors are weakly correlated and greatly vary by climate, especially in areas away from the coasts where peak conditions can be extreme when compared to degree-days. In the projects completed since 2007 it was found that designers for projects outside of marine climates used the annual-demand route for calculations 92% of the time whereas projects within marine climates used annual-demand 42% of the time. Annual demands can be lowered further in the U.S. than in Europe through over-glazed façade designs because of the greater solar resource [5].

The objective of the study conducted by the DOE and Technical Committee was to validate climate-specific passive house standards and criteria for space conditioning (limitations on heating and cooling loads) while preserving a high level for energy reduction targets and remaining economical feasibility within the region of construction. The three standard principles of focus in the study were:

Airtightness – criteria for superinsulation of building envelopes that assures prevention of moisture intrusion that can lead to failures of construction.

Source Energy – cost competitive levels for heating and cooling load limits with a focus on conservation.

Space Conditioning – requirements structured to guide designers toward passive measures.

2.2. *Airtightness*

The airtightness criteria standard was reviewed against climate data due to concerns about moisture intrusion and mold risks with an airtight building. The proposed change is from a limit of 0.6 ACH50 to 0.05 CFM50 per square foot of gross envelope area (or 0.08 CFM75). This allows the airtightness requirement to scale appropriately based on building size [5].

2.3. *Source Energy*

Limits on source energy were reviewed with consideration of global carbon dioxide emission budgets set by the Intergovernmental Panel on Climate Change (IPCC). Changes were proposed for accuracy and fairness in calculating energy limit factors such as:

Per-person limitation has been set as opposed to the previous square foot of floor area in residential projects.

Correction of the source energy factor to 3.16 for grid electricity in the calculation protocol for consistency with the United States national average.

Lighting and miscellaneous plug-load default of 80% of the Residential Energy Services Network standard has been adopted.

Source energy limit is set to 6200 kWh per person per year and the committee will be looking into tightening that requirement to 4200 kWh per person per year in a few years.

Allow for onsite photovoltaics or other renewable energy systems to be accounted for the same way as solar hot water by applying the limit on the source energy to the calculated net of the estimated fraction of onsite renewables [5].

2.4. *Space conditioning*

Space conditioning criteria was considered from an economic feasibility standpoint with changes proposed, such as:

A shift to climate-specific mandatory thresholds for annual heating and cooling demands and peak loads that help to target a “near-optimal sweet spot with slightly more energy savings than Building Energy Optimization (BEOpt) software’s calculated optimum cost. This change and use of BEOpt will ensure efficiencies will be reasonably cost-competitive.

The reference floor area will be simplified, representing “an inclusive interior-dimension floor area” [5].

The results of studying these updated measures provides a performance-based, cost-effective standard that will reduce the national average energy consumption in buildings by approximately “86% for heating and 46% for cooling, with a peak load (systems size) reduction of 77% and a peak cooling load reduction of 69% as well as total source energy reductions for buildings consistent with limiting global temperatures from warming by more than 2 degrees Celsius” [5].

To achieve these savings, heating and cooling load limits calculations were restructured to be climate responsive. It is recommended that designers use Building Energy Optimization (BEopt) Software developed by National Renewable Energy Laboratory (NREL) for residential construction pursuing passive house and net zero. The tool assists designers in developing a climate specific energy saving design that is cost optimized using the National Residential Energy Efficiency Measures database embedded in the program. The software will provide the heating and cooling load performance data and will “curve fit that data to local climate parameters such as degree-days and design temperatures. The optimizations are constrained with strict requirements on air-tightness, and minimum window U-values, to ensure that building durability and winter comfort are not compromised in the search for energy savings” [5].

Formulas derived from the study for each climate type can be used in energy models to help set the criteria for heating and cooling as long as the climate information for the location is known. Previously set energy and airtightness standards were evaluated and changed to be scalable with the building envelope’s surface area rather than volume of interior space and space conditioning criteria remains the same. Residential projects source energy calculation will be scaled per person and based on design occupancy.

PHIUS has published an online climate specific performance targets data tool for the United States as a result of the study. This tool is searchable on a map with more than 1000 locations identified with performance metrics calculated to help designers arrive at a climate specific design that is energy aggressive and cost effective (see Figure 1).

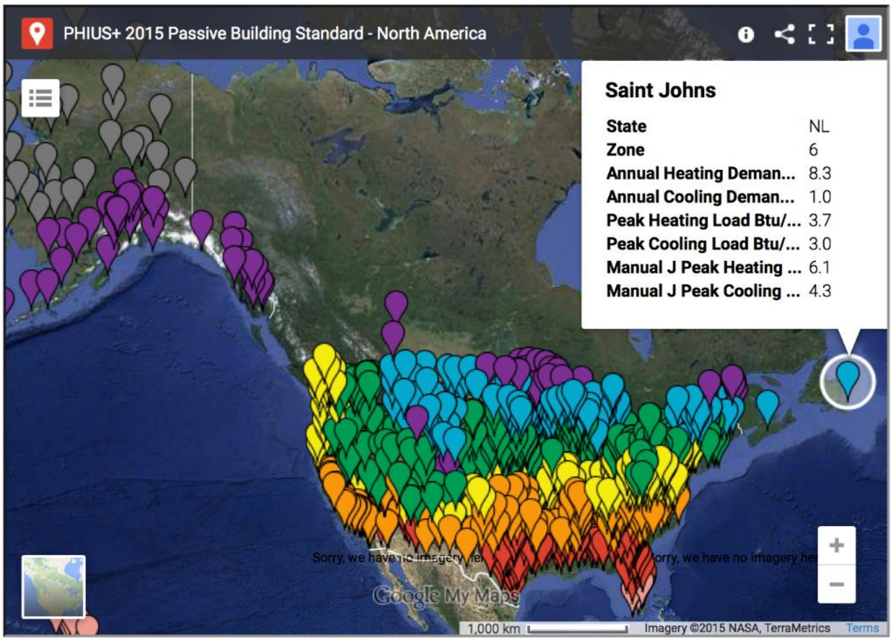

Figure 1: Passive House Institute of the United States – Passive Building Standard, climate specific targets data map [6].

As a result of this study DOE and PHIUS has provided a road map to design buildings for net zero that is better suited for specific climates found within the U.S. In designing a Passive House facility design teams take an integrated approach that will still focus first on passive means of improving the building through its envelope design then selecting mechanical equipment that will further target reductions in heating and cooling energy use [7].

3. Conclusions & Future Research

Without the oil crisis of 1973 prompting the need for energy independence and a focus on conservation of natural resources, the building sector would be contributing the higher energy consumption rates without concern for sustainability or resilience. Today Passive House Standards are in place as well as other stringent regulations and standards that are required by select municipalities and for government projects. Additionally, proactive owners who want to lower their consumption and save on energy costs are also demanding changes in the way buildings are designed, constructed, and operated.

This paper presents the Passive House Standards that have been utilized in the building sector largely for residential and smaller commercial construction for nearly two decades in Europe and one decade in the U.S. Much has been learned through the successes and failures of buildings entering the Passive House certification process throughout various climate zones. Successful achievement of certification in the past has been challenging for buildings in locations of extreme climate types. The acknowledgement and study of Passive House Standards and climate zone application by the PHIUS Technical Committee and the DOE is a step in the right direction for inspiring design teams and owners in other regions to pursue nearly net zero and net zero designs.

The recommended changes to the Passive House Standard as a result of the study is an area that could be studied further for application particularly in hot-humid climates and cold climates where relying on passive principles mainly with reduced mechanical assistance has been cost-prohibitive in many cases. Study of other energy efficient designs and experimental technologies implemented in buildings located in these climate zones were reviewed as a part of this research and would be valuable to study against a traditional passive house approach for comparison. Case studies in these regions could prove additional or alternative passive house principles are necessary for building design in these locations.

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Responsible Research and Innovation in Construction

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Abstract

The issue of ethics and responsibility is gaining attention among the creators of scientific policy, funding agencies and society at large. Responsible research is defined as research that aligns both the process and the outcomes with the values, needs and expectations of society. In an EU funded project "Responsible Research and Innovation in Information and Communication Technology (ICT)" a four dimensional framework for defining and monitoring responsibility in that kind of research projects has been defined. The four dimensions are (1) actors who are responsible or to whom research is responsible, (2) kinds of responsibility – in what way are they responsible, (3) how much they are responsible and (4) in what area of ICT responsible research and innovation can take place. After presenting the framework we apply the concept of responsibility to research in the field of architecture, engineering and construction (AEC). We are finding that the particular feature that sets responsibility in construction apart from other research topics is the impact it has on life and safety of large number of people and on the critical infrastructures. While responsibility is important we conclude with a warning that the first responsibility of research is scientific quality and that other responsibilities cannot be a substitute for that.

Keywords: construction research, research policy, innovation, responsibility, social responsibility, scientific method

1. Introduction

With the increasing power of scientific development and impacts of the new discoveries on the planet in general and on society and humans in particular, the issue of ethics and responsibility is gaining attention among the creators of scientific policy, researchers and society at large. The topic has been particularly relevant in some fields of life sciences which are tackling the very fabric of life and the very features that make us human. But the concept is spreading to other fields as well. Among the reasons is the need of funding agencies and policymakers to present the case for societal value of research that is being publicly funded.

Responsibility is broader concept that that of ethics that has been present in life sciences for decades if not centuries. The idea of responsibility has been emerging in European and national research programs for a long time but more intensely in this century. In 2001 "Science and Society Action Plan was created". In 2010 "Science in Society (SiS)" emerged. In 2010 the RRI concept was defined as a response to aspirations and ambitions of European Citizen as a part of the effort to better justify the public investment in research and innovation. In 2014 the idea of RRI in ICT made it into the programmatic document of Horizon 2020. The concept made big advances from the baseline idea, which would claim that the only responsibility of research and innovators is to do good quality research.

2. Responsible research and innovation

The European Commission defines responsible research as "an inclusive approach to Research and Innovation (R&I), to ensure that societal actors work together during the whole research and innovation process. It aims to better align both the process and outcomes of R&I, with the values, needs and expectations of European society. In doing so, it fosters the creativity and innovativeness of European societies to tackle the grand societal challenges that lie before them, while at the same time pro-actively addressing potential side-effects" [1].

It goes on in saying that “In general terms, RRI implies anticipating and assessing potential implications and societal expectations with regard to research and innovation. In practice, RRI consists of designing and implementing R&I policy that will: engage society more broadly in its research and innovation activities, increase access to scientific results, ensure gender equality, in both the research process and research content, take into account the ethical dimension, and promote formal and informal science education”.

On the other hand, another European institution, the Economic and Social committee, stated a concern [2] that the RRI might in fact harm the freedom of the mind achieved by the Enlightenment and wrote »What is needed is a fundamental change in social attitudes, so that innovations are not seen primarily as a risk or a threat, but rather as an opportunity for further progress, more jobs and European economic strength and competitiveness, and for shaping the European social model.«

The author is involved in a project “Responsible Research and Innovation (RRI) in Information and Communication Technology (ICT)”, funded by the European Commission as a part of the Horizon 2020 program. The project has been set up under the assumption of major impact that ICT research has on society and aims at monitoring, analyzing, supporting and promoting RRI approach in ICT research in Europe [3]. The goals of the project are to (1) promote a contribution of social sciences and humanities to RRI in ICT under Horizon 2020, (2) curate the RRI domain in H2020 empowering projects and other stakeholders, (3) facilitate the interaction for the emerging RRI-ICT community and (4) create a networking platform – real and in cyberspace - where stakeholders would meet and exchange views.

3. RRI Framework

We are defining the RRI concept through mapping. We present a 4-dimensional map of RRI in ICT. The dimensions define (1) who and to whom are actors responsible, (2) what the responsibility is about, (3) how much responsibility there is and (4) to what topic of ICT the responsibility applies.

The **actors** (who) include researchers, funding agencies, policymakers, educators, students, society at large, all either as individuals or in groups or institutions.

The **kinds** (what about) include epistemic responsibility, procedural responsibility, social responsibility, ethical responsibility and finally the legal & financial responsibility [4]:

Epistemic responsibility is to deliver good science, a responsibility that the community of scientist should take care of for their own deontology and career, by making a proper use of the scientific method and source of knowledge in the research; also includes freedom of thought and pursuit of ideas unlimited by limitations of the church or a state.

Social responsibility is responsibility to the needs of society and their challenges and about the outside impact of research and innovation. It is that is primarily a responsibility towards citizens and society that is sometimes channeled into research program priorities, topics and research project goals.

Ethical responsibility is towards a set of established values and norms that in principle represent an “higher being” (i.e. they are beyond the interests and stakes represented by any single actor), but in practice may be identified with the norms and values prevailing in the societal context where research and innovation is done (e.g. with fundamental rights and safety protection levels set by the EU, the UN Chart of Human rights, etc.). It is responsibility towards the planet, living beings, life etc.

Procedural responsibility is responsibility to ensure an open, inclusive, transparent and fair engagement of all stakeholders (including the citizens) affected by research and innovation activities, the latter in particular to be involved because they contribute as tax payers (when the research is publicly funded) and as prospective users/customers of the research results. It includes openness of research findings and openness of research processes for example to women and minorities.

Legal and financial responsibility is about the contractual obligations the research institutions may establish with funding agencies, about regulations and laws needed to introduce new products and services on the market, and new evidence-based policies enforced through legal acts taken by public authorities.

Levels of responsibility range from being unaware of RRI (as a distinct concept) to establishing systematic procedures to maintain and increase the levels of responsibility within an actor [ibid.]:

Not aware about the idea of responsibility, but perhaps doing something about it intuitively. An example of that would be natural tendency to disseminate research, report it on conferences and events, thus making it more open.

Aware of the idea of responsibility and using that occasionally to improve on it. An example would be know the big challenges and include the tackling of them in research that is unfolding.

Aware and systematically practicing responsible ways of doing things. An example of that would be organizational efforts to maintain compliance with rules and regulations.

ICT **topics** are an important dimension because particularly the social and ethical aims may be quite different for different kinds of technologies being developed. Big data research, for example, would have different responsibility requirements than, for example, high throughput computing.

An evaluation of levels of responsibility by topic of responsibility could be depicted on a diagram as the one in the Figure below.

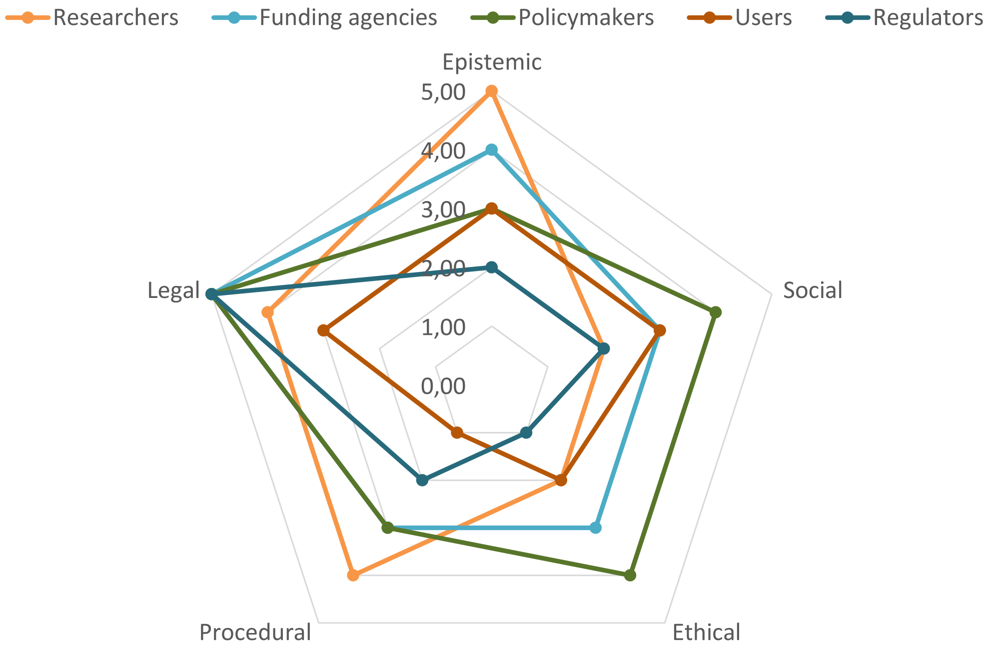

Figure 21: RRI footprint in ICT structured according to the RRI framework and based on informal impression of the consortium members.

4. Responsibility in Civil and Structural Engineering Research

Civil engineering and construction research too has a significant external impact. There is some literature that demonstrates the awareness of construction of the concepts of responsibility, for example in construction management [5][6]. More work, however, is related to ethics [7][8], social responsibility [9] and teaching of engineering ethics and responsibility [10][11]. In the rest of this paper some themes that could be studied with relation to the kinds of responsibility and construction research will be outlined.

4.1. *Epistemic responsibility*

This responsibility is related to doing quality scientific work. The challenge for research in architecture, engineering and construction (AEC) is that the area is so diverse that several scientific methodologies could be deployed. And it would be irresponsible to deny this fact or, for one or the other reason, pick a method which is inappropriate. Some topics in AEC research require the scientific method of natural sciences. They study how materials or structures behave under external influences. Mathematical or computer models can be verified by experimentation and observation. Other topics study social or socio technical phenomena. For example how people interact in projects, how they communicate and collaborate. Modelling and experimentation is possible, but a model may change what is being observed. Methods of social sciences, such as organization sciences or economics are appropriate.

And then there is problem solving research – a need to solve an original engineering problem, hopefully, but not necessarily such where solutions could be reused. Fallibility of this kind of research is in a direct contradiction of the engineering approach to problem solving which is finding a workable solution with the means that are available.

It is also irresponsible to evaluate engineering research using same metrics or criteria regardless of the topic and research method.

4.2. *Social responsibility*

This responsibility is related to addressing societal challenges and societal needs. The author identified five such challenges and opportunities in which AEC research would have a role in addressing them [12]: (a) Automation and abundance, (b) BRICS and globalization, (c) Climate change, (d) Demography and (e) e-technologies. Each has a huge potential for engineering research. In some topics we contribute to pushing the state of the art, for example in automation, which also leads to problems such as abundance and restructuring of the labor market. Engineering research could be responsible about all five areas. It would be responsible, for example, to automate dangerous and unhealthy jobs, to solve, as a part of globalization process, housing needs in developing countries with efficient solutions; to contribute in the mitigation and adaptation to climate change; to take part in creating attractive places to live and work for families and migrants so as to tackle the demographic problem; and to shape the e-technology revolutions with the solutions specific for the construction industry.

In addition to addressing those five areas of new challenges, the responsibility is also towards traditional concerns of AEC – to provide safe, healthy and resilient infrastructure, housing and workspaces. Resilience is perhaps the most important issue that a responsible researcher would not overlook.

4.3. *Ethical responsibility*

What perhaps sets AEC apart is the ubiquity, broadness and long-termism of AEC products. They are everywhere, they will remain there for decades, even centuries. A lot of resources and energy are used to produce them, they take space which is a very limited resource.

4.4. *Procedural responsibility*

In the aspect where it concerns the stakeholders, again, AEC research touches everyone. Stakeholders are all those using the built environment. A particular challenge is that consumers often do not have a choice, as they do with discrete, movable, expendable consumer products. We do not get rid of AEC products as fast as we can replace a failed design of – say – a mobile phone. AEC infrastructure is shared, not only privately owned.

4.5. *Legal and financial responsibility*

A possible peculiarity and difference here could be the stakeholder (and potentially funder) demographics. For AEC industry small and medium enterprises are the rule rather than an exception.

5. Discussion and Conclusion

The concept of responsible research and innovation that has developed for another discipline has been presented. It includes four different dimensions of responsibility. The concept was being verified so as to think about the responsibility in AEC research along those dimensions. It has been found out that the scheme is generic enough to do so. However, the topics or responsibility, particularly the social responsibility are heavily influenced by peculiarities of the AEC industry.

While it is tempting to improve the responsibility of research this should not happen at the expense of the quality of research. In other words – not all responsibility topics are equally important and responsible research in not the sum of all responsibilities. The primary responsibility of researchers is to do high quality, methodologically sound research. If it is, in addition, socially responsible and contributes to solving some societal problems, even better. But funding agencies and policymakers should not be tempted to award researchers doing poor work about the correct issues.

Acknowledgements

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Derivation of Seismic Risk Function for Critical Infrastructures

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Abstract

Critical infrastructures importance to the society and the economy is constantly rising due to the increasing dependency of the private and public sector on the services they provide. Critical infrastructures are complex and interdependent systems; thus, damage to one component in the system can lead to a total failure of the CI and consequently lead to disruptions of other CIs. Therefore, there is an utmost importance to ensure reliable performance of critical infrastructures on a continuous basis and particularly after the occurrence of earthquakes. With the understanding that it is unfeasible (economically or physically) to ensure full robustness of the system for all possible scenarios, decision makers are required to plan the upgrade of the systems accordingly to the most efficient strategies and corresponding to the economic limitations.
In this study, a methodology is developed to appraise the risk that CIs are exposed in case of earthquakes and to act as a decision support tool for decision makers to manage efficiently the courses of action to mitigate this risk. In this methodology, Probabilistic Seismic Hazard Analysis (PSHA) approach is used in order to reflect a variety of possible seismic scenarios and overcome the uncertainties regarding to the timing, the location, and the magnitude of an earthquake. The seismic vulnerability of the component is evaluated by fragility curves and Fault-Tree-Analysis.
The seismic risk function of the system is derived by an aggregation of the occurrence probabilities of the earthquake, seismic vulnerability of the different components, and the expected consequences. The derived risk function expresses the expected risk of the system for a given ground motion intensities that reflect different possible earthquake scenarios. Using this methodology, different mitigation strategies can be examined and prioritized accordingly to their contribution to the risk reduction and relatively to each strategy cost.

Keywords: critical infrastructures; earthquakes; fragility curves; risk assessment

1. Introduction

Critical Infrastructures (CI) play a crucial role in the normal performance of the economy and society. Over the last decades the amount and the variety of critical infrastructures grew rapidly, and the interdependency between them increased constantly; consequently, more and more essential services depend on the continuous performance of one, two or even more critical infrastructures such as power, water supply, communications, etc.

As was observed in previous studies, there is a significant gap between the stability and the preparedness level of CIs for seismic events and the actual damage that those facilities are exposed to in a case of a seismic event [1-3]. The consequences of the latest seismic events emphasize the importance to mitigate the seismic risk by increasing the preparedness of CIs and ensuring reliable and robust performance on a continuous basis, particularly during and after the occurrence of extreme events. Implemented mitigation strategy is derived accordingly to the financial limitation and depends on decision makers' policy. Therefore, at first, in order to clarify the actual risk that CIs are exposed to in case of seismic event the risk should be quantified. Subsequently, in case the risk is not acceptable, different mitigation strategies must be examined in order to select the most optimal strategy, respectively to the financial feasibility.

The major objective of this research is to develop a probabilistic methodology that examines the preparedness of critical infrastructures through an appraisal of the risk that CIs are exposed in case of seismic events and provide a decision support tool for risk mitigation. Prior methodologies for risk appraisal [4-6] presented procedures that

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offer tools such as fragility curves, fault tree analysis, logic tree in order to appraise the risk of different components. Those methodologies presented tools to appraise the risk for existing generic infrastructures based on empiric data. However, those studies didn't examine different mitigation strategies and their effectiveness on the risk reduction and didn't conclude to the optimal strategy. Moreover, those methodologies are mainly used in order to appraise the risk as a result of a specific earthquake event.

This methodology is intended to expand prior risk appraisal tools such as fragility curve and fault tree analysis and implement them as a decision support tool for policy makers. This methodology intended to quantify the seismic risk by a probabilistic seismic analysis of a variety of possible seismic scenarios and examine different mitigation strategies in order to conclude the most optimal mitigation strategy under the given financial constraints.

2. Methodology

The proposed methodology is composed of five main steps; each one of the steps produces values or curves which are essential for the overall risk appraisal process.

2.1. *Seismic Hazards Identification*

The seismic threat for each CI's component is identified according to the location of the facility according probabilistic seismic hazard analysis (PSHA) as presented by [7]. The PSHA approach is intended to consider all possible scenarios according to geological data about the possible earthquake sources, and the probability of magnitude and intensity occurrence that is associated with those events. The PSHA approach requires ground-motion attenuation models that estimate the expected ground-motions at a given site as a result of different intensity and location earthquakes. This step yields an Annual Rate of Exceedance curve (PE_A) as a function of a given ground motion intensity measure (IM); when in most cases, for above-ground structures the IM is expressed in term of peak ground acceleration (PGA) [8-10].

2.2. *System's Seismic Vulnerability*

In this step, the expected damage state as a result of a seismic event is formulated in terms of fragility curve. The fragility curve expresses the probability of reaching or exceeding certain damage states for a given level of IM [11-14]. This function is fully defined by determination of two parameters: median capacity of the component to resist the damage state (θ) and standard deviation of the capacity (β).

$$P[DS \geq ds|IM = x] = \Phi\left(\frac{ln(x/\theta_{ds})}{\beta_{ds}}\right) \; ; ds \in \{1,2, \dots N_D\} \tag{2}$$

Eq. 1 expresses a formulation of a fragility function. When P stands for a conditional probability of being at or exceeding a particular Damage State (DS) for a given seismic intensity x defined by the earthquake Intensity Measure (IM). Where,

DS	Uncertain damage state of a particular component. {0,1,... Nn}
ds	A particular value of DS
N_D	Number of possible damage states
IM	Uncertain excitation, the ground motion intensity measure (i.e. PGA, PGD, or PGV)
x	A particular value of IM
Φ	Standard cumulative normal distribution function.
θ_{ds}	The median capacity of the component to resist damage state ds measured in terms of IM
β_{ds}	Logarithmic standard deviation of the uncertain capacity of the component to resist damage state ds

2.3. *Damage Assessment due to seismic Extreme Events for different components*

This step associates a damage ratio (DR_i) with each damage state; the DR_i expresses the percentage of the total replacement value of a component corresponding to damage state i. Subsequently, since the damage ratio is associated directly to the damage state, the expectant damage ratio of a component (DR_c) can be calculated as follows:

$$DR_c = \sum_{ds} DR_i * P(ds_i|IM) \tag{3}$$

Where

DR_i	Damage rate of the damage state i
$P(ds_i \mid IM)$	Conditional probability of being in a certain damage state i for a given IM

Furthermore, the expected repair cost (RC_c) of the component for a given IM can be calculated regarding to the replacement value (RV_c); when the RV_c expresses the total replacement cost of the component. Thus, one can calculate the expected direct damage of the component for any given IM as follows:

$$RC_c(IM) = RV_c * \sum_{ds} DR_i \cdot P(ds_i|IM) = DR_c * RV_c \tag{4}$$

2.4. *Risk Appraisal according to expected damage*

The product of this step is a seismic risk curve, that present the expected annual risk for any given value of IM. Since risk represents the potential impact and loss and it is defined as the product of the occurrence probability and the expected consequences, this curve is constructed by multiplying the annual rate of exceedance curve with the direct damage curve by matching between the PGA values in both curves and link the expected consequence and its probability to occur. This matching produces a curve that correlated between the expected damage in terms of annual expectancy of risk and the PGA.

$$R_A(IM) = RC_c(IM) \cdot PE_A(IM) \tag{5}$$

Where

$\mathrm{R_A}(IM)$	Annual risk for a given IM
$RC_c(IM)$	Replacement cost of the component for a given IM
$P\mathrm{E_A}(\mathrm{IM})$	Annual rate of exceedance of a given IM

2.5. *Risk Mitigation*

In this step, different mitigation strategies are examined in order to predict the effectiveness of the mitigation strategy on the preparedness level of the CIs by quantifying the reduction of risk followed by implementation of each strategy. Each examined mitigation strategy has different effects on the robustness and the resilience of the system which is reflected in different parameters of the fragility curve; those changes will effect on the level of risk. Subsequently, the optimal strategy is selected according to the level of reduction of risk and economic considerations.

3. Case study

The annual rate of exceedance curve depends on the specific location of the facility. Therefore, in this case, the facilities are assumed to be located in Beer-Sheva, Israel. As well, the cases are performed according to a simplified annual rate of exceedance curve (Figure 22), which was derived based on the values that were published by the Geophysical Institute of Israel report [15]. In this report, the attenuation is based on the model of [16] which has a good correlation to the middle east seismic patterns. This attenuation model considers a sufficient range of magnitudes (4-8.5) and allows to consider the effects of weak seismic areas. Moreover, this attenuation considers main parameters of site effect such as: Magnitude (M), distance from rupture (R), fault mechanism, and soil stiffness. In this chapter, two example cases of implementation of the methodology for CIs components are presented: (A) steel storage tank and (B) Oil pumping plant.

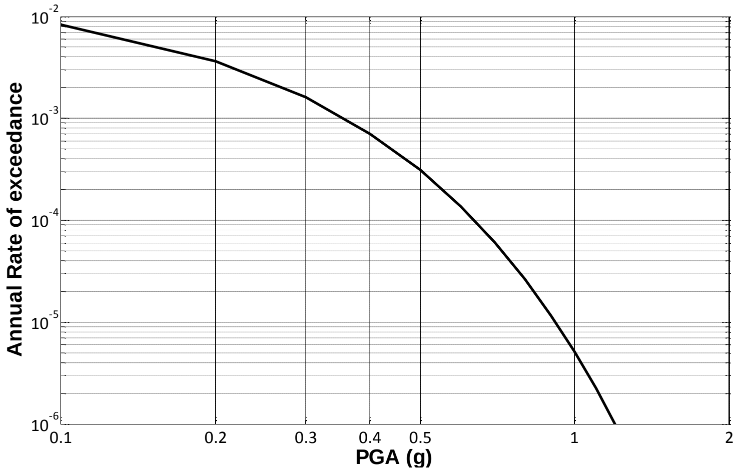

Figure 22 - Annual rate of exceedance curve for west Beer-Sheva region

3.1. *Case study A –Steel storage tank*

This case study implements the proposed methodology on an oil steel storage tank. Oil storage tanks are used for storage of different petroleum products for a long or a short time; often, several storage tanks ate concentrated under the envelope of an oil farm. The modern oil storage tanks are varying from 12-76m in diameter with heights to diameter ratio (H/D) is mostly lesser than one. The most common design type of tanks is cylindrical ground-supported tank due to their efficient resistance to hydrostatic pressure and can be easily constructed [5, 10, 17, 18]. In addition, most of the oil storage facilities are composed of welded steel with floating roof.

Several fragility parameter sets are offered by the literature based on empirical data [19]. [4] provides data for steel tanks categorized the tank only whether it is anchored or unanchored. In addition, [6, 8, 20] suggest to consider parameters such as H/D ratio and fill level.

In this case, the fragility parameters are based on the values proposed by [8] for tank with H/D ratio lesser than 0.7, since most of the storage tanks in Israel are complying with these criteria. According to those values the fragility curves are composed (Figure 23). The damage ratio of the tank is based on the best estimate damage ratio that proposed by HAZUS [4]. In addition, the full replacement cost of a single tank is estimated at 800 thousand US$.

Table 20. Damage states description and parameters of a steel tank as proposed by [8] and damage ratio values based on [4]

Damage state (Ds_i)		Damage Description	θ	β	DR_i
Ds_1	Slight/minor	No damage to tank or inlet/outlet pipes	0.67	0.50	0.20
Ds_2	Moderate	Damage to roof other than buckling, minor loss of contents, minor damage to piping, but no elephant's foot buckling	1.18	0.34	0.40
Ds_3	Extensive	Moderate Elephant's foot buckling with minor loss of content, buckling in the upper course	1.56	0.35	0.80
Ds_4	Complete	Elephant's foot buckling with major loss of content, severe damage, broken inlet/outlet pipes	1.79	0.29	1.00

Following those parameters (Table 20), the risk function is derived by an integration of the annual rate of exceedance curve with the fragility curve, DR_c and RV_c. The risk curve (Figure 24) shows that the intensity ground motion PGA at a range of 0.25-75 has a major contribution to the total annual risk expectancy. However, the risk expectancy is relatively low, as could be expected due to the low probabilities to exceed PGA over 0.6g at the site and the values of the fragility curve that express low vulnerability of the steel tank for low-moderate ground accelerations.

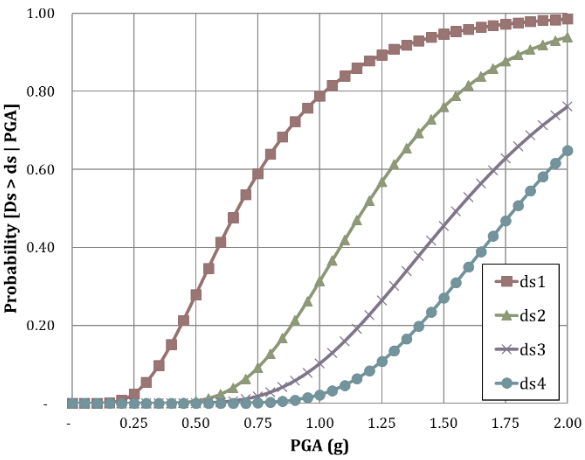

Figure 23 - Fragility curve for steel tank

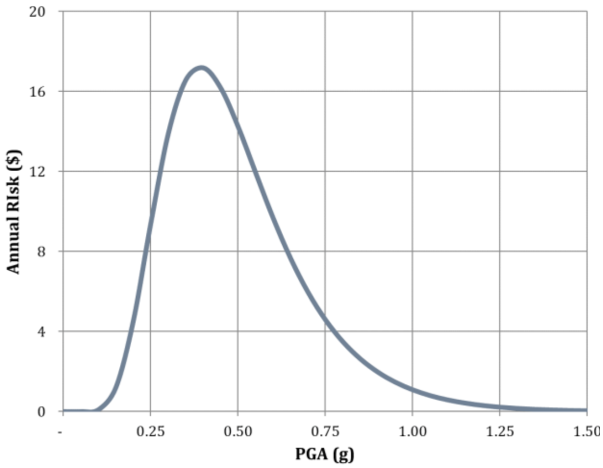

Figure 24 - Risk curve for steel tank

3.2. *Case study B – Oil pumping plant*

Pumping stations serve to maintain the flow of oil across pipeline system. They are located at certain intervals along the pipeline network to ensure the transport over long distances and around the storage facilities when the pressure must be increased due to friction losses. In addition, Pumping is also required to transport oil uphill wherever this is required by topographic conditions.

According to [6] the failure of a pumping plant is most likely to occur as a result of damage to one of its main sub-components: the building, one or more pumps, electrical equipment, and electric power and backup systems. Regarding to pumping stations, the anchorage of the subcomponents is a key point, as unanchored equipment can lead to breaks of the equipment and the piping.

In this case, the fragility parameters are based on the values proposed by [4] for unanchored pumping plant (Figure 25). The damage ratio of the tank is based on the best estimate damage ratio that proposed by [4] and the full replacement cost for a pumping plant is estimated at 1M US$.

Table 21.Damage states description and parameters of an oil pumping plant and the damage ratio values as proposed by [4]

Damage state (Ds_i)		Damage Description	θ	β	DR_i
Ds_1	Slight/minor	Defined by light damage to building	0.12	0.60	0.08
Ds_2	Moderate	Defined by considerable damage to mechanical and electrical equipment, or considerable damage to building	0.24	0.60	0.40
Ds_3	Extensive	Defined by the building being extensively damaged, or pumps badly damaged.	0.77	0.65	0.80
Ds_4	Complete	Defined by the building being in complete damage state	1.50	0.80	1.00

Following the above parameters (Table 21), the risk function is derived by an integration of the annual rate of exceedance curve with the fragility curve, the damage ration (DR_c), and the replacement value (RV_c). The risk curve analysis shows that low-moderate ground accelerations, where the exceeded PGA is lesser than 0.8, have a major contribution to the total annual risk of the pumping station (Figure 26).

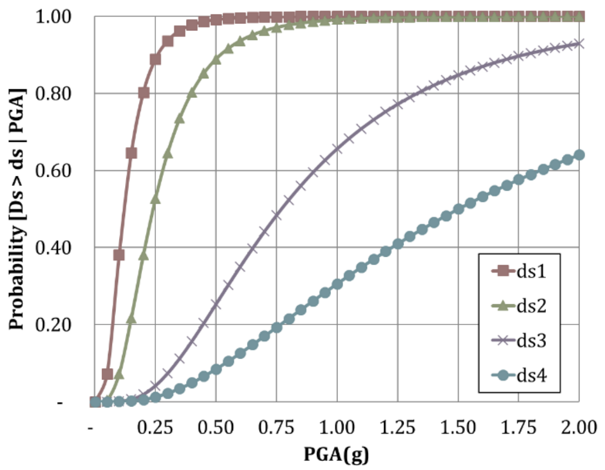

Figure 25 - Fragility curve for pumping plant

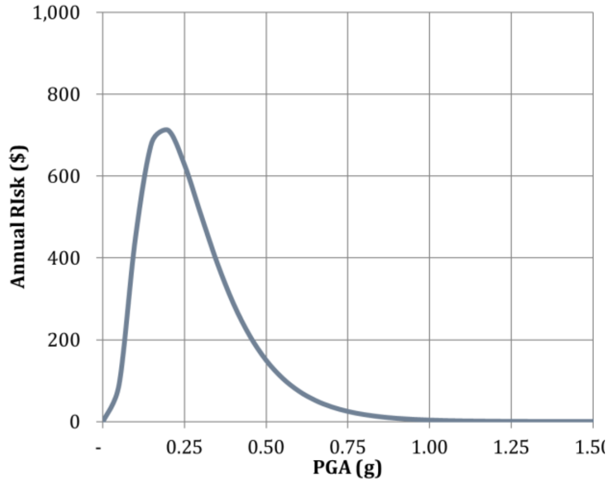

Figure 26 - Risk curve for pumping plant

One of the possible methods to reduce the potential damage of the PP in case of seismic event is anchoring the subcomponents of the station. This strategy is increasing the resistance of the subcomponents to overcome moderate level ground accelerations and subsequently increases the robustness of the pumping plant for seismic events. Implementation of this strategy modifies the fragility curve parameters for ds_1 and ds_2, which gives a relatively high probability to exceed this damage states in case of moderate ground for the unanchored plant while anchoring the subcomponents reduces the probabilities to exceed ds_1, ds_2 in case of moderate ground accelerations (Figure 27). This mitigation strategy reduces the total risk of the pumping plant. The reduction is manly effect the damage that expected as a result of moderate ground motion. A analysis of the derived risk curves for unanchored and anchored plants shows that anchoring the components can reduce the risk by about 27% (Figure 28).

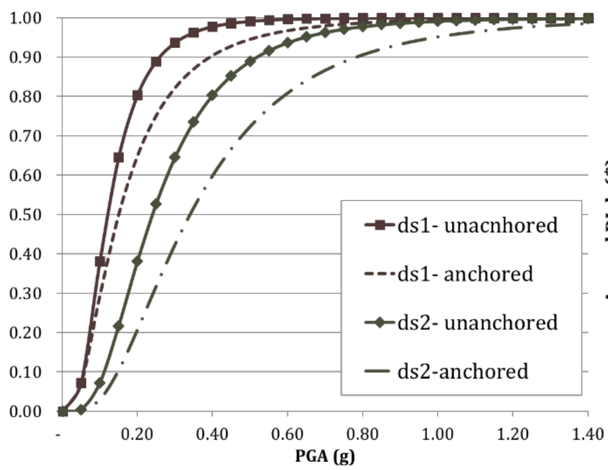

Figure 27 - Comparison of ds_1 and ds_2 for anchored and unanchored pumping plant

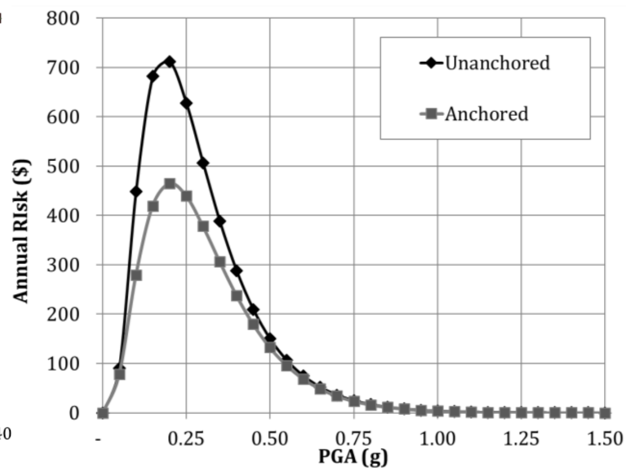

Figure 28 - Comparison of the derived risk curve for anchored and unanchored pumping plant

4. Conclusion

In this paper a probabilistic risk appraisal methodology is introduced and presented. The methodology appraises the expected damage to critical infrastructures components using fragility curves. The occurrence probability of different-intensity seismic events is estimated according to probabilistic seismic hazard analysis (PSHA) approach. Then, the annual risk expectancy is calculated as a product of the annual rate of exceedance and the expected damage for a given IM.

This paper presents an implementation of this methodology through two case studies: oil tank and pumping plant. The oil tank case illustrates a good example that the overall risk is determined according to two main factors: seismic vulnerably of the system and probability of occurrence. Since the tank is mainly vulnerable to high ground accelerations on the one hand and the probability to exceed those ground accelerations is low, the risk expectancy of the tank is relatively low. The second case demonstrates the seismic risk expectancy of a pumping plant. In this case, the risk expectancy curve reveals that the majority of the risk is concentrated at the low-moderate peak ground accelerations levels. A possible mitigation strategy was examined and the subsequent reduction of risk was analyzed. It was found that anchoring the subcomponents of the pumping plant can reduce the risk expectancy by over 25% at the most critical range of ground accelerations.

The methodology presented in this paper is intended to be used as a decision support tool in for management and priority setting of mitigation strategies based on the seismic risk expectancy that critical infrastructures are exposed to and according to the level of risk reduction of the mitigation strategy and the Benefit to Cost Ratio analysis.

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BIM and Safety Rules Based Automated Identification of Unsafe Design Factors in Construction

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Abstract

Design for Safety (DfS) has been considered as an effective approach to improving construction safety performance via taking into account safety problems during design. The approach, however, is not yet implemented effectively and efficiently in practice. This research tries to develop a practical DfS approach, which can automatically identify potential safety problems resulted from design by integrating BIM (Building Information Modeling) with design safety rules. Design safety rules related to construction safety is defined and built based on design regulations or codes, and a BIM and safety rules integrated approach developed to implement the automated identification of safety problems. Furthermore, a test-bed project is presented to test the validity of this approach. As a result, the unsafe factors in design can be detected during construction to aid in construction safety management on site. Compared with traditional safety management methods, the BIM-based DfS approach is automated, thus reducing the time and labor cost spent on safety checking and improving the performance of construction safety management.

Keywords: Building Information Modelling(BIM); construction safety; design for safety(DfS); safety rules

1. Introduction

Construction safety is a serious issue in the construction industry, which has been one of the most dangerous industries. Design for Safety (DfS) is regarded as an efficient approach to reducing safety problems in construction. That is, safety problems could be identified during design. According to Reason[1], some factors that have negative effects on construction safety may be arisen in the conceptual design stage, and then may deteriorate to accidents in construction processes. Gambates also found that 40% of construction accidents were related to design through the analysis of 224 construction accidents and confirmed that there exists the causal relationship between design and accident [2, 3].Thus design has an serious influence on construction safety, and construction accidents can be prevented through considering unsafe factors in design.

From the perspective of Design for Construction Safety(DFCS), safety issue should be considered during the course of design , so as to eliminate design-related safety problems. Behm found that DFCS can eliminate nearly one third of potential safety hazards, 50% of which are directly related to unsafe design[4-6]. The key point of implementing DFCS is to make it timely and confident for architects and engineers to identify potential safety problems in design. In order to achieve this, some research has been conducted. For example, Yuan applied DFCS in subway design, but lacking detailed research on the content of safety knowledge base[7]; Kim structuralized the workers-oriented design proposal to check the design proposal with safety-hazard-identifying software[8]; Choi developed a rule-based automatically checking system to share drawings and documents information by integrating standard for the exchange of product model data and extensible markup language format document[9]. These research mainly focuses on improving designers' safety knowledge or integrating design proposal, rather than safety rules aiding design.

It may be feasible to identify safety problems based on the basic rules of design, which depends on design regulations, including experts' knowledge and experience. Most of design regulations are closely relevant to construction safety. For example, according to a safety regulation, a rectangle hole needs to be covered to avoid

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falling accidents if the length of a shortest side is from 2.5 cm to 25 cm. Thus design regulations effects not only design, but also construction safety. Thus design, regulation and construction safety are closely related in the whole construction process. The International Code Council (ICC) also proposes to identify potential errors of construction documents based on safety rules [9].

This paper focuses on how to realize a safety rule-based way to identify unsafe factors during design. A safety-rule base is established by categorizing unsafe design factors and analyzing the relationship of regulations, design and construction safety and a coding rule for safety rules built. Based on the above two steps, safety rules and building information are translated into machine-readable language and compared automatically by computer to identify potential safety hazards in design period based on the safety rules base.

2. Safety rule of design

Safety regulations and codes are the foundation of construction risk identification. To realize automatic risk identification, it is significant to match BIM components or activities with relevant safety regulations and codes. A safety rule system is thus built by 1) classifying construction safety information, 2) building a safety rule system and 3) translating safety rule system to machine readable language.

Different kinds of regulations may categorize unsafe design factors from different perspectives and may describe the same rule in different format. To facilitate rule searching, it is essential to reorganize these rules in the same format and same system. But all of these regulations can be classified into safety protection, design calculation and design checking. As the rules are used to prevent safety accidents, the design safety related information is reorganized according to accident-related attributes. A framework of safety rule system can be developed based on the organized items. Table 1 shows the framework of safety rule system.

Table 1. Framework of design safety rules.

Safety rules	Example
Accident type	Fall
Accident subject	Hole
Attributes	Vertical
Parameter	H=0cm
Safety rules	Safety Guards
Regulations	Unified Code for Safety Technology in construction 5.3.2
Prevention measures	Handrails

To facilitate information retrieval, safety rules are coded according to accident type, accident subject and other properties. Each safety rule is given a unique number ID, which can be understood by computers. Each safety rule code contains five parts: rule types, accident types, accident subjects, attributes, rule number and item number, as shown in Figure 1[10].

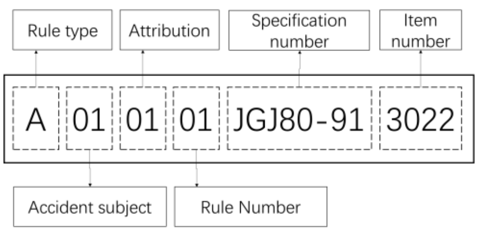

Figure1.Coding method for design safety rules

3. Coding of design components

To realize automatic comparison of design information and safety rules, design components should also be coded. To ensure the uniqueness of component ID, an ID consists of two parts: name ID and data ID. Name ID contains information about accident types. For example, the doors of a BIM model have a same name ID. Data ID contains information related to component parameters, including accident type, accident subject, key words and other information. The system will first determine the type of accidents according to name ID, and find out of the related rules. Then the data ID will offer the component's properties, which are in turn used to be compared with safety rules.

By matching component ID and safety rules, unsafe design factors can thus be identified, and the locations and time of these factors will also be recorded. Finally, designers can improve their designs according to the record.

4. Integration of safety rule and BIM

To realize the integration of safety rules and construction information, a tool is needed to store and manage the information related to building and construction process. BIM, a visualized and digital construction information database is applied due to the following reasons:

Digital construction information. BIM contains the design information of each components, and the information is digitalized, which can be extracted easily by programs.
Well-organized construction information. The information stored in BIM is categorized by components. It is an important characteristic, as the design information in the proposed system is also sorted by components. Thus the information stored in a BIM model can be directly combined with the system without reorganization.
Parameterized construction information. BIM is a parameterized model, which means if you modify one parameter of one component, all the relevant parameters will be changed automatically. This character will facilitate the modification of unsafe design factors a lot. For example, if you reduced a window opening, then the size of the window will change as well.
Visualized construction information. BIM is a visualized model, which helps designers and safety managers to find and rectify unsafe factors more easily.

By comparing safety rules and the building information stored in BIM, unsafe design factors can be identified and visualized in building information model. Based on the visualized identification results, designers are able to improve design proposal directly or share the results with contractors to improve construction planning. Besides, the identification reports can be used continually in construction safety management on site.

Figure 2 presents the process of integrating safety rule system and BIM. First, safety rule database is integrated with building information model. Then component ID is matched with safety rules ID to identify accident subjects in the model. Then the system will compare component parameters against safety rules. If dangerous area is found in design, relevant design information will be recorded and a prevention will be given. Table 2 shows an example for possible checking results.

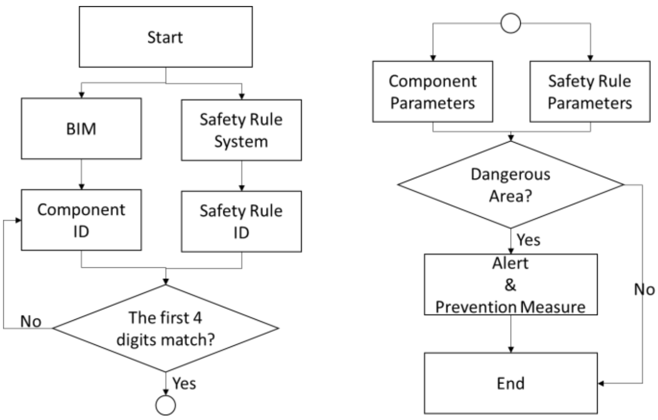

Figure 2. Automated identification of unsafe design factor based on safety rules and BIM

Table 2. Automated record of unsafe design factors identified (example).

Component ID	Parameter	Rule code	Position	Prevention measure
01010001	R<=2.5cm	A01-0101JGJ80-91-3022	(x,y,z)	Null
01010002	R<=25cm	A01-0102JGJ80-91-3022	(x,y,z)	Cover
01010003	R<=50cm	A01-0103JGJ80-91-3022	(x,y,z)	Cover
01010004	R<=150cm	A01-0104JGJ80-91-3022	(x,y,z)	Steel bar protection net
01010005	R>=150cm	A01-0105JGJ80-91-3022	(x,y,z)	Handrail and protection net

5. Experiment and demonstration

In order to demonstrate the feasibility and validity of the BIM-safety rule-integrated approach to automatically identifying unsafe design factors, a test platform is customized by combining Autodesk Revit and Unity 3D. IFC (Industry Foundation Classes) is applied as the basic standard for BIM modeling.

As an experiment, the windows of a four-story building was used to test the above approach. At first, the BIM model of the building was built with Autodesk Revit. During the modeling process, component ID was configured for each of components (windows). Other parameters, e.g. position and size, can also be easily extracted from BIM model, as shown in Figure 3.

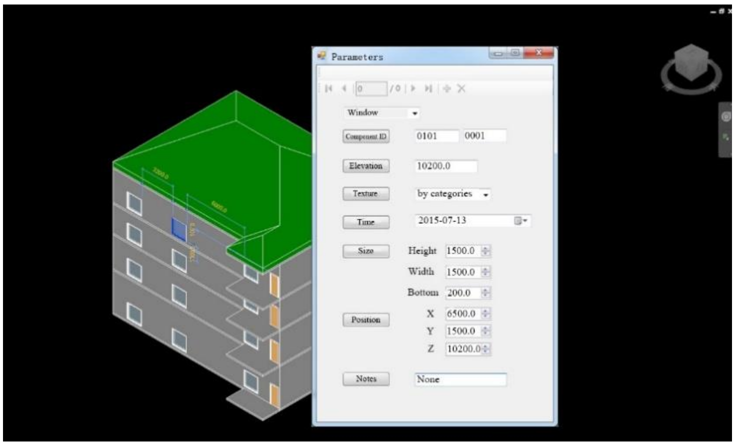

Figure3. Properties of windows extracted from BIM model.

Then the building information model was imported into Unity 3D, which has been linked with design safety rules. With the aid of a script, the Unity platform extracted the window's component ID - "0101", and searched for the safety rules with the ID like "A01-01XXXXXXX-XXXX". As a result, the attribute parameters of this window was compared with the safety rule. In this case, as the window's elevation is higher than 1.2m and its height and width are all larger than 1.5m. According to safety rule A01-0104JGJ80-91-3022, a 1.2m-high guardrail is needed, thus being recommended as shown in Figure 4.

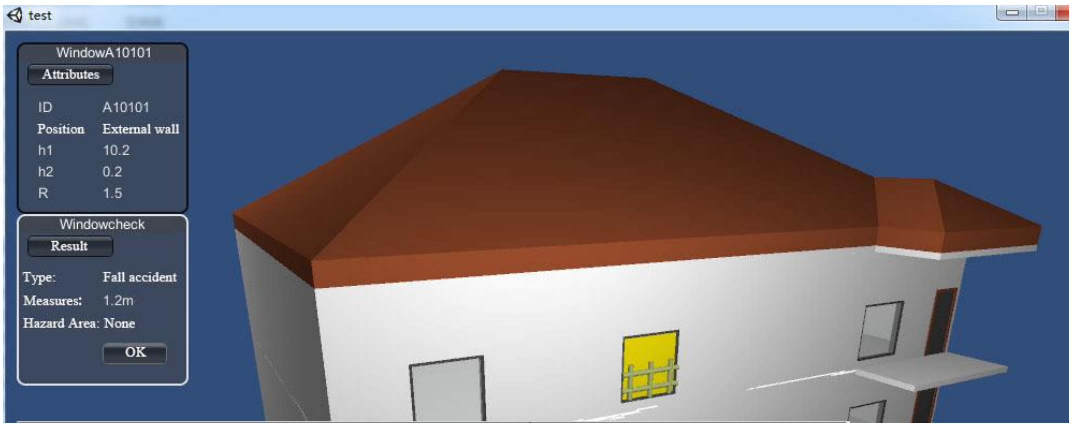

Figure 4. Identification results of the unsafe design factors of windows

6. Conclusion

As shown in this paper, construction safety is a serious issue in construction industry. Design for safety, which means take safety into consideration during design period, is considered as an efficient method to solve this problem. However, due to the dynamics and complexity of construction projects and the diversity of safety-related rules, it is difficult to identify unsafe design manually. To solve this problem, a safety rule and BIM based platform is developed to identify and rectify unsafe design automatically.

The proposed platform is realized by the following procedures:

A safety rule system is built by categorizing safety rules and then extracting basic and necessary information from them. Besides, each rule is attached to a unique code.
Each component is matched with a unique component code, which represents its properties and parameters.
Components information is extracted from BIM and each component is paired with safety rules by matching component ID and safety rule ID.
By comparing component parameters and related information in safety rules, unsafe design factors are identified and rectified.

Based on the above framework, an experiment is executed and prove the feasibility of the framework. However, a fully developed platform is expected to be developed by enrich the safety rule system and allow the safety identification of a dynamic construction process.

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A Review of Building Information Modelling for Construction in Developing Countries

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Abstract

Building Information Modelling (BIM) is widely seen as a catalyst for innovation and productivity in the construction industry. BIM can assist a more sustainable construction that in turn may contribute to eradicating poverty in developing countries (United Nation Millennium Goals). While BIM is increasingly being adopted in developed countries, implementations in the developing country context are rare. Research has established how construction firms struggle from several limitations having to do with the socio-economic and the technological environment found in developing countries. Examples of issues preventing BIM adoption include a shortage of IT-literate personnel as well as an absence of national BIM implementation programs. Based on a review of recent research, this article addresses some of the hurdles and solutions for BIM implementations particular to low- and middle-income economies. Findings include that developing countries' construction firms rely on outsourcing of IT services or developing tweaks or workarounds, like using 'fake' IT licenses, for saving cost and enabling BIM. The article highlights shortcomings of existing research on BIM implementation in developing countries, and may serve as a starting point for researchers interested in how BIM technology can be adopted in a developing country context.

Keywords: barriers; Building Information Modeling; construction; developing countries; implementation strategy

1. Introduction

According to the World Bank [1, 2], there exist 135 middle- and low-income economies referred to as developing countries. These countries face large knowledge gaps and can be characterized by limited and occasional technological innovation [3]. In developing countries, construction is a labor-intensive industry. Wells [4] reported that the average construction output per person in low-income countries is just about one-ninth of that in high-income countries. Besides, construction is also considered as the most material intensive [5]. A variety of existing challenges lead to delays, poor site environments, poor working conditions, low quality, and accidents in developing country construction [6]. The low efficiency of construction in developing countries implies a promising area for development. Because construction could assist a more effective employment of human and material resources, the industry is often considered as a driver for growth and achieving development goals [7-9].

Like other industries, the construction companies benefit from a range of information and communication technology (ICT) solutions when delivering their projects. It has been suggested that construction projects will be more effective and productive with ICT applications [6]. One of these ICT applications is Building Information Modelling (BIM), which could have many benefits in supporting construction. In terms of more effectiveness and productivity, BIM yields advantages for scheduling, design, implementation, and facility management. From a stakeholder perspective, BIM helps owners, designers, contractors, and management teams to collaborate, visualize and manage construction work better [10]. Consequently, BIM technology receives significant attention from practitioners. In the light of improvement, increasing the use of ICT could help to address some of the currently experienced challenges. The implementation of construction ICT in general and of BIM in particular should be considered in the developing country context. Based on a review of recent research, this article thus focuses the following research questions: What is the current state of BIM implementation in developing countries, and what further research is required for advancing this? Addressing these questions is worthwhile for researchers and practitioners focusing on firms operating in developing countries, seeking to reap BIM's benefits.

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1.1. *ICT implementation in developing countries*

Information and Communication Technology for Development (ICT4D) is a research area in the information systems (IS) literature. Examples of this research include the study of healthcare systems, the internet, and e-procurement systems in developing economies. What unites this research is the focus on overcoming the recurring limitations and barriers for ICT adoption in developing countries. Some of the frequently mentioned ICT implementation challenges typical for developing countries are management related. Such issues include: qualified personnel, financial support, strategic perceptions, market support, social cultural environment, and security concerns. In addition, there are technical challenges such as: lack of framework, policies and procedures for adoption. Lack of research and development also hinders ICT implementation [11-14].

While many of the managerial and technical barriers would seem familiar from the study of ICT implementations in developed countries, some appear unique for developing countries. Security concerns are likely to be the most noticeable case, since software piracy is widespread in developing countries. Aleasa et al. [15] reported that the 25 countries with highest piracy rates are exclusively developing countries. Using cracked software, organizations may unintentionally be exposed to viruses and hacker attacks that could lead to unexpected disruptions and unmanageable damages. This article explores the implications of the aforementioned challenges for organizations operating in the architecture, engineering and construction (AEC) industry in their BIM implementations.

1.2. *BIM implementation framework*

The framework chosen for structuring the literature review was suggested by Jung and Joo [16], and developed from an application of IS planning methodology in construction. In the attempt to assess the effectiveness of IS in construction, the authors stressed managerial and technical issues, aiming to address all relevant BIM issues. The framework can be summarized as follows:

Table 1: The framework categories (adapted from Jung and Joo [16])

Technical (T)	**Perspective (P)**	**Construction Business Function (C)**		
1. Data Property 2. Relation 3. Standards 4. Utilization	1. Industry 2. Organization 3. Project	1. R&D. 2. General Admin. 3. Finance 4. HR. mgt. 5. Safety mgt.	6. Quality mgt. 7. Cost control 8. Contracting 9. Materials mgt. 10. Scheduling	11. Estimating 12. Design 13. Sales 14. Planning

- [T1] Data Property covers the technical aspects of geometric and non-geometric BIM data, their arrangement in databases, and their metadata with construction material objects being classified.
- [T2] Relation deals with the technical interdependency of data properties in parametric BIM objects. Moreover this category deals with technical aspects of file exchange (i.e. industry foundation class file exchange format)
- [T3] Standards include BIM studies exploring technological aspects of file exchange and related standards such as ISO, Uniclass, and MasterFormat.
- [T4] Utilization entails studies seeking to develop the technological aspects of BIM to better support practical project level use of BIM. Here the different construction disciplines contribute studies on how to make BIM a technologically better system for its respective purpose.
- [P 1, 2, 3] Perspective covers overview studies focusing the industry, organizational and project wide diffusion of BIM.
- [C 1-14] Construction Business Function covers studies focusing on BIM's effect on organizational performance and work in different aspects of the construction supply chain. This stream of research takes into account how BIM and IS influence the day-to-day operations in the construction industry and projects.

2. Methodology

A literature review is an extensive reference providing background and justification to the conducted scholarly works in a specific research field [17]. This paper contributes an update of BIM implementation in developing countries. To collect relevant literature, a 6-step literature search process was adopted [18]. (1) The search focused on peer-review outlets. Moreover, as conference papers usually are of lower quality and less mature than journal articles, only journal articles were considered [19]. No restriction to specific journals was made, to provide an overall view of scholarly work in the area. (2) The search was conducted in the Elsevier Scopus database, the largest database for peer-reviewed abstracts containing over 57 million records. (3) The topic keywords informing the search were "Building information modelling" and "Building information modeling". Geographical keywords were "developing countries" and the specific names of 135 developing nations. Topic keywords were connected to each other by using the Boolean operator "OR". Likewise, we linked the geographical keywords by "OR". Only English language articles were considered in our study leaving aside potentially relevant work published in other languages. (4) A limitation of this work is that we did not consider the impact and influence of articles in terms of citations. (5) The initial return of the search were 39 articles. However, through initial screening for topical relevance we excluded articles not having to do with BIM in construction (i.e. biomedical engineering etc.), leaving a total sample of 27 articles (6) This was followed by a full text evaluation to categorize the collected articles according to the BIM implementation framework presented in table 1. After step (6), two more articles were excluded. One article was about a hospital BIM design case study in the Middle East, but the task was outsourced to a design team in the US [20]. The other excluded article [21] was an on-going study by Enegbuma et. al. because their latest work was included in the sample. Thus, a total of 25 articles were classified. For articles covering several topics, only the main focus was used for classification. The main focus was identified by reading what specific purpose was stated in the article. Table 2 summarizes the search conducted.

Table 2: Scopus search summary

Keywords	[1] ((Building information modelling) OR (Building information modeling)) AND ((developing countries) OR (developing country)) [2] ((Building information modelling) OR (Building information modeling)) AND ((countries*))		
Database and date assessed	[1] Elsevier SciVerse Scopus assessed 15.12.15 [2] Elsevier SciVerse Scopus assessed 15.12.15	Return	2 37
Scopus search strings	[1] (TITLE-ABS-KEY({Building information modelling} OR {Building information modeling}) AND TITLE-ABS-KEY({developing countries} OR {developing country})) AND DOCTYPE(ar) AND (LIMIT-TO(LANGUAGE,"English")) [2] (TITLE-ABS-KEY({Building information modelling} OR {Building information modeling}) AND DOCTYPE(ar) AND (TITLE-ABS-KEY(countries*)) AND (LIMIT-TO(LANGUAGE,"English"))		
Number of relevant articles: 27			
* names of 135 developing countries as defined by the World Bank.			

3. Findings

Sixty-four percent (16/25) of the articles were published in the last two years. This can be viewed as an increasing interest on BIM implementation in developing countries. Among the 135 developing countries, BIM implementation studies were only reported in China (13), Malaysia (9), and India (3), indicating a research gap regarding the other 132 countries. Figure 1 shows the distribution of articles by country over time. An overview of the classification results based on the framework by Jung and Joo [16] can be found in table 3. Table 4 presents frequently mentioned keywords classified by article topic area. In what follows the results of our review are presented by topic area.

Figure 1: BIM studies in developing countries

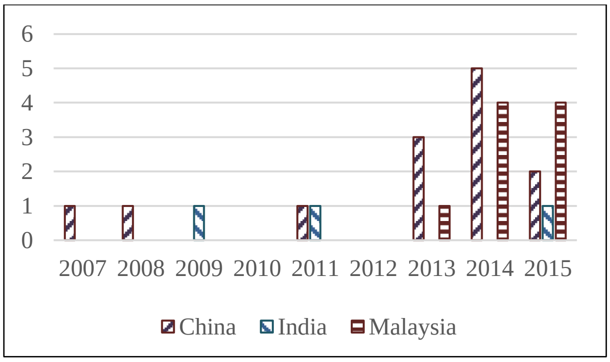

Table 3: Classification of articles

Dimension	**Articles**	**Percentage**
Technology	12	48 %
T1-Data property	1	4 %
T2-Relation	0	0 %
T3-Standards	4	16 %
T4-Utilization	7	28 %
Perspective	7	28 %
Construction Business Function	6	24 %
Total	**25**	**100 %**

Table 4: Mentioned terms

T1-Data property	As-built, cloud computing, construction management, data management, facility management
T3-Standards	Cost estimation, engineering contract, Industrial foundation classes
T4-Utilization	As-built, carbon footprint, construction management, construction safety, facility management, geographic information system (GIS), terrestrial laser scanner (TLS)
Perspective	Construction management, industrialized building system, information technology strategy, participant involvement, Structural equation modeling, sustainable construction
Construction Business Function	Innovation adoption, innovation diffusion theory (DOI), Institutional theory, integrated project delivery (IPD), lean construction, parametric modeling technology (PMT), technology acceptance model (TAM)

3.1. *Technical*

Viewing all technically focused articles together (T1-T4), we find a relatively strong focus on technology in developing countries (48% of all articles). Maybe not surprising, there are several studies focusing on the alignment of technological standards, taking into account national, regional and local regulations and legislation. Moreover, making BIM a technically better tool to support its utility for developing country construction firms receives much research attention. From the classification of the articles it appears that technological relation (T2) topics receive no research attention in developing countries.

T1 – Data property: Claiming that data management in construction and facilities management is challenging, Jiao et. al. [22] suggest a "cloud application model", namely LubanWay, enabling data sharing and gathering. This cloud computing model was applied and developed for facilities management in the Shanghai Tower. LubanWay can be used to combine engineering and management data, collect data, and proves "particularly effective in cost control"[22].

T3 – Standards: The identified studies focused on transferring BIM standards to the developing country context. This includes studies on how international BIM standards (e.g. AEC/UK or openBIM), can be adapted to the Chinese national context. There are presently no legal barriers for utilizing such standards in China as long as these are specified as contract addendum to the tender document [23]. Scholars have studied how industry foundation class file exchange (IFC) following the openBIM method can be employed in developing country civil engineering projects [24, 25]. This would allow for tighter integration across several different engineering systems [25], as well as aligning different estimation methods [24]. The findings are promising as they show that BIM has the potential to "significantly reduce" workloads and errors in civil engineering projects in developing countries [26].

T4 – Utilization: When implemented in projects, BIM provided design support resulting in overall reduction of design time [27, 28] and clashes [27]. However, it was evident how issues of low data quality and poor coordination hinder effective BIM utilization [29]. How Terrestrial Laser Scanning and Geographic Information Systems data could be merged with BIM for creating 3D as-built visualizations receives attention from developing country researchers [28]. Other areas focused in this category include: BIM's utility for increasing construction safety [30], how to drive construction efficiency by deploying BIM [30], and how to overcome hurdles for BIM-based collaboration across companies [28]. Finally, sustainable or green construction is another area of BIM research and "energy saving and carbon reduction" [31] as well as "energy conservation" in the early construction design stages are studied in the developing country context [32].

3.2. *Perspective*

BIM implementation surveys in developing countries can be found at industry, organizational, and individual levels. A survey of the Chinese industry surfaced that BIM was primarily viewed as useful for promoting contractor competitiveness [33]. Organizational BIM adoption levels in Malaysia and China remain low, with less than 20% of the surveyed construction organizations applying BIM in practice [34-36]. Moreover, even when BIM has been implemented in individual construction companies, its usage is limited and still in its "infancy" with many barriers to be tackled [35]. Taking a technical view, practitioners would need to improve "the compatibility and integration" between BIM and current construction software [35, 37]. Moreover, BIM use would need to be in alignment with daily construction activities [35]. Presently, BIM is viewed to be fairly complex and difficult to use [38]. In addition, developing country firms view BIM as a 'risky' investment since its business value remains unclear [33]. While practitioners appear interested in BIM adoption they appear unwilling to change the status quo in their firms [38]. Drivers such as "economic benefits" and "effectiveness and efficiency" could motivate these practitioners [37]. BIM needs to be supported from clients, contractors and government before it will become used in developing countries [33, 38]. Moreover, technical training is viewed as important to drive BIM implementation [37].

3.3. *Construction business function*

Theories frequently applied in IS research such as Institutional theory, TAM and DOI are also used to investigate how to implement BIM in practice. A survey of 92 construction projects in China revealed that coercive or "authoritative pressures" have a great impact on the attitudes of clients/owners towards BIM adoption, while architects and contractors were mostly motivated by mimetic pressures seeking to imitate "successful conduct" of others [39]. Furthermore, practitioners' BIM adoption intentions were influenced by their "willingness and interest" [40]. Entrepreneurs viewed IPD based on PMT as promising avenues for improving their ways of doing business. IPD was considered a good approach for achieving tighter integration in developing country construction projects [41]. PMT was viewed as essential basis for a better alignment of design technologies [42]. Utilizing relational database systems allows graphical and non-graphical data to be managed in one system. Such information infrastructure will support to manage, capture, and represent project data in a dynamic way [42]. Moreover, BIM systems still allow users to continue generating traditional two-dimensional paper drawing sets [42]. However, BIM adoption continues to be low in developing countries [35]. Some barriers typical for developing countries are limited financial resources for IT investments, lack of national BIM standards, and inexperienced modelers [40]. Moreover, developing country firms are so far not convinced as to whether BIM usage will provide acceptable returns. An attempt to develop a model for evaluating construction IT application in general, and BIM implementation in particular, has been presented in the literature [43].

4. Discussion

Most of the articles included in the review have been published in the last two years, showing how researchers in developing countries have just begun to explore BIM topics. When comparing the extent of this work to the BIM research efforts undertaken in developed countries over the past two decades, it is reasonable to claim that this work is still in its infancy. Moreover, research interest so far appears to be limited to China, India, and Malaysia. Thus, the findings presented in this article need to be viewed against the background that there exists little BIM related research from other developing countries.

Technology - The articles have their main focus on transferring available BIM technology to the developing country context. Researchers focus their inquiries mainly on 'vanilla' implementations of commercially available BIM software packages made by software vendors located elsewhere. A notable exception from this trend is the LubanWay [22] software developed by a local Chinese software developer. Evidence from developed countries indicates that off-the-shelf BIM solutions will need some degree of customization and/or 'add-ons' to best fit the realities of local legislations and building traditions. Taking Norway as an example, there exists a range of commercially available BIM add-on software packages providing Norwegian construction companies with digital object libraries featuring construction materials typically used in Norway. Moreover, software packages for energy or costing solutions are developed to fit the realities of the national Norwegian context. Judging from the articles reviewed, there appears a need for researching and creating local BIM software adaptations customized for the various developing countries. This constitutes an important area for further research.

Perspective - There are relatively few instances of practical BIM use reported in the developing country context. However, in China, India, and Malaysia, there are cases of BIM use similar to what is done in advanced projects elsewhere (e.g. the Shanghai Tower). However, in terms of industry wide BIM diffusion, China has fewer than 20% percent of its AEC firms reporting BIM use, whereas the US has BIM adoption rates of above 70% [44]. In absence of data on BIM diffusion in other developing countries, we also draw upon the insight from the first author, after working several years for a Vietnamese metro administration. According to his experience, in Vietnam there are very few cases of BIM use, and if ever used then it is by Japanese and Korean consultants working in the projects. This indicates a need for further research mapping BIM uptake in other developing countries. This could be done based on existing BIM capability and maturity indicators.

Construction business function - The research classified under this sub-topic studies what can be gained by BIM implementation in different parts of the building construction supply chain in developing countries. Like their peers in developed countries, scholars from developing countries have argued for how sustainability, construction management and logistics could all benefit from increased BIM use. While conceptual studies from India and Malaysia debate BIM, GIS, and TLS integration [28, 30], studies exploring BIM use in transportation (roads, bridges, metro, etc.) and facilities (water pipes, sewers, etc.) projects are absent. Considering the importance of transportation and facilities projects for development, researchers should consider conducting further work in this area. Moreover, it is somewhat surprising that there are few studies seeking to address the major barriers for BIM implementation in developing countries, similar to what is done in ICT4D research. This can be viewed as a limitation of the present work that would need to be addressed before BIM can be implemented successfully.

5. Conclusion

From the systematic review in this article, an overview of BIM research in developing countries has been provided. Almost no research on BIM in developing countries exists prior to 2013, and the focus of the present work is limited to the three countries of China, India, and Malaysia. Further, the scope of the work appears to be limited to technology transfer research topics seeking to import technology, standards, and collaboration approaches to the context of developing countries. Limited attention is given to BIM implementations in infrastructure and facilities projects in developing countries. This leads us to conclude that more work is needed to develop new BIM solutions that address the context of the local construction industries in developing countries better.

In general, more studies are required to cover the gaps identified in this paper. Technological and managerial aspects to enhance BIM implementation are also promising for further work. We propose to conduct research in developing countries and the framework dimensions (T1 and T2) that are under-represented. From the technical view, approaches or requirements for collaboration such as openBIM will be essential to focus in further studies. From the managerial view, an effective strategy for BIM implementation in developing countries should gain more attention. In this vein, a comparison between developed and developing contexts is applicable.

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A BIM Template for Construction Site Planning

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Abstract

Building Information Modelling is gradually becoming the standard method for building design all over the world. Its rapid development is visible not only in the many researches carried on it but also in the several standards released in different countries. The spread of the method implied continuous software improvements with the aim to comply as much as possible different design needs. Nevertheless, an insufficiency of tools specifically developed for construction site planning is still detectable among BIM panorama. The principal aim of the presented research is then to develop BIM use for making more efficient construction site design. Having defined, in an early report, the structure and the contents of the postulated Construction Site Information Model, the research goes on by customizing the available tools in order to fit the needs of a construction site designer. One of these tools is a predetermined template, useful as a starting point for the design, as it is for other design disciplines. The aim is to have at disposal, since the beginning of the project, a model completed of a series of elements, parameters, visualization tools and many other issues able to satisfy the needs of construction site design in term of information contents, level of detail and model efficiency. A step-by-step procedure is also provided to assure the correct use and guarantee the completeness of the model. In particular the research steps has been the following: (i) analysis of some software to evaluate the chances of customizing templates; (ii) creation of the template according to the defined contents and aims of the Construction Site Model; (iii) test and improvement of the tool in a project simulator specifically created for the purpose; (iv) practice in real case study and evaluation about its operation. The case study permits to evaluate how this tool make more efficient site designer task in term of time spent and mistakes avoided.

Keywords: Building Information Modelling; Construction site planning; Construction Site Information Modelling; Design optimization; Project Template.

1. Introduction

It is a redundancy to say nowadays that Building Information Modelling will prevail soon on CAD applications, which are at now well established in our design trends. Software vendors dealing in the construction sector have already adopted this trend by providing a large number of software concerning with BIM design approach. This trend answer also to the numerous public administrations that, since many years, requires the use of BIM methodology as a mandatory. The need to develop in detail each part of a building project pushed BIM vendors to provide and add “discipline specific interface, objects, design rules and behaviors to the same base parametric engine” [1]. Then, each main design discipline (in particular architectural, structural and MEP) has its particular design methods according to the software used. Current research moves also to other and more specific disciplines such as energy analysis, facility management and also construction site design and management. In particular this paper shows a part of an ongoing research concerning with BIM application and implementation to enhance construction site planning in each phase of design process. The main goal is to develop an efficient way to develop site plan able to guarantee the construction site expectations in term of costs, time and workers safety needs. Efficiency means, in general, reduction of design effort and errors through a software assisted planning as well as a continuous interoperability between the site planner and other designers in order to assure the feasibility of each work.

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Academic research analyzed many different aspects of site and works planning trying to implement it in a BIM environment. Vimonsatit et al. [2] underline the possibility to enhance site planning thanks to simulations and BIM that shows available spaces throughout the construction stage. However this research focuses on a problem on a lack of serious design tools that do not leave the choices entirely to the knowledge of the users. Lot of the researches the concerns construction sites are indeed focused on construction scheduling (with the implementation of 4D models) and safety planning. In particular from many years researches on 4D scheduling have been carried out starting from 4D CAD tools [3] to 4D BIM and use of data to generate schedules [4]. The 4D tools and the resulting possibility of construction phases visualization permit a detailed design of construction works taking into particular consideration, first of all, safety aspects. However planning for safety has been considered an important task in the satisfaction of the project needs. As an example a great importance has given to the construction workspace management [5] and their interferences [6]. In general the main goal is to facilitate safety planning production [7] ensuring a detail level suitable for hazard identification before starting construction. Other researches focused also the need of a creation of parametric objects libraries of temporary structures [8] and equipment [9] with the aim of a BIM site planning optimization. However the research on the field often focuses on single aspects of construction planning (safety, scheduling, costs, etc.). The presented research aims instead to go ahead single applications and give an overview of the construction site design process by developing a method supported by different tools for the site designer.

One of these tools -specifically developed for the purpose by the task group of A.B.C. Dept.- consists in a BIM project template able to help site designer during the modelling of the construction site in all its aspects. To be more clear, a definition of what we intend as a “BIM project template” is provided since the term should have different meanings according to the used software. Then, we intend as a template a BIM model of a specific authoring software specifically prepared for a particular task. It means that this “starting” file is provided by specific settings for the users to start a project in a certain discipline. It is important to underline that some software (e.g. Revit) permit to have a specific file (e.g. *.rte) format that represents the template to be used in a model file (e.g. *rvt). Some of these software already make available some starting templates for different disciplines (e.g. architectural, structural or MEP templates) provided with the elements of that specific discipline (e.g. furniture, beams, ducts) as well as specific modelling settings. As showed in the next paragraph other software (e.g. allplan) do not have this possibility, but a customized file can be used as a template to start each project. The research carried out on these software shows that a large part of them provides, in different ways, some settings that help the modelling for the different design disciplines, but nothing specifically developed for construction site layout planning.

In our on-field experience the use of a template entails, instead, a great time saving in design. Therefore, the paper will focus on some requirements to provide in a template in order to facilitate site planning. We identify these requirements in a series of elements, parameters, visualization tools and many other issues able to satisfy the needs of construction site design in term of information contents, level of detail and model efficiency.

In order to be clear the requirement have been translated directly in a model template following these research steps.

- software analysis and evaluation of the chances of customizing templates;
- creation of the template according to the defined contents and aims of the Construction Site Model;
- test and improvement of the tool in a project simulator specifically created for the purpose;
- practice in real case study and evaluation about its operation

2. Creation of the template

2.1. *Software analysis*

Having evaluated the importance of templates availability in terms of efficiency in project production, the research moves on the analysis of some BIM authoring software in order to evaluate the possibility of implementing templates in different disciplines. The analysis takes into consideration six software (see table 1) that, obviously, do not cover the entire BIM panorama but give a general idea since they are the most diffused. The first step of software evaluation takes into consideration the general chance to start a project with a predetermined template file and to customize it according to user needs. The second step of the study goes more in detail and gives a view about how is possible to customize a template in two different ways. This step consider both the possibility to use a proper template file or to use a project file as a template. The first one concerns the possibility of having available some object and tools useful to make faster the modelling of design choices. The second one concerns, instead, the possibility of add some elements and tools in order to facilitate the production of clear deliverables such as sheets and schedules. In particular, the first step analyzes the possibility to have available a definite layout as well as objects and materials libraries focused on a specific design discipline; while the second step analyzes the possibility of customize sheets layout or line and text styles. The whole investigation is carried on by literary and users' research as well as some tests carried on some of the analyzed software. Table 1 summarizes the results of software analysis. From this study is visible how Revit permits more flexibility in customizing templates and so it was used for the development of the template, its simulation and the case study. However the arguments faced took into account the possibilities of other software.

Table 1. Project templates characteristics for major BIM authoring software.

Template characteristics \ Software	AECOsim Building Designer	Allplan	Archicad	Revit	Tekla	Vectorworks
Templates availability	•		•	•	•	
Templates customization			•	•	•	
Elements libraries	•	•	•	•	•	
Materials libraries	•	•	•	•	•	•
Schedules and reports	•			•	•	
Styles		•	•	•		•
Drawings			•	•	•	•

2.2. *Pilot template creation*

The process of creating a template customized for construction site planning starting from the analysis of the needs of a construction site designer. An early report of research [10] focused on the contents of a postulated Construction Site information Model (CoSIM) in different design stages. It was the starting point for the creation of a template that aims to facilitate each step of the construction site design structure. The template creation consisted in the customization of graphical and informative settings of a BIM (in this case a revit template file) in order to be used to each construction site project.

Regarding *Project Contextualization* the settings consist in some graphical properties that permit to identify and evaluate the site constraints that can affect the construction site. Therefore, the template contains some parameters that identify the constraint (e.g. aerial constraint) and the graphical setting give to the element (e.g. a tree) a specific color that permits to immediately identify the constraint itself.

Regarding *Functional-Spatial* and *Technological-Plant* design the template contains a series of pre-made construction site BIM elements (e.g. equipment, temporary structures, machineries, etc.) in order to have them at disposal directly from the software without searching in computer storage. The libraries are divided into different level of detail according to design phase analyzed. For this reason, a specific template refers to a specific construction design phase. Also in this case some graphical tools are added in order to simply identify the type of element in order to directly evaluate, for example, cost classes (e.g. cost for work, cost for safety, etc.).

Concerning *Process analysis* and *Process planning* the template contains settings that permit to automate the view of some parts of the designed building according to construction phases in order to evaluate site and works layouts in each phase. For these issues the template was also set up in order to automatically extrapolate quantities of construction elements to calculate times and costs.

For what concern *Organizational modelling* and *Health & Safety coordination plan* the template contains all that issues useful for deliverable production such as sheets settings (pen styles, customized titles, position of views and information, etc.), data tables to be inserted in design documents, etc..

According to the postulated CoSIM structure [10] these are the contents of the three CoSIM pre-design phase. The creation of the templates for the CoSIM-execution design followed the same criteria with a level of detail suitable to this design phase. In order to assure the correct use of the template a step-by-step procedure, specifically written for the purpose, permits to follow the design flow in different stages. The procedure, as well as the template itself, born according to a project simulator used for the development and implementation of the presented tool.

3. Test on project simulator

In order to better understand the usefulness of a project template in construction site design this paragraph present its use in a project simulator. It consists in a specific project created with the aim to develop and refine the templates before testing it in a real case study. In particular the project simulator shows the development of the contents of CoSIM pre-design in preliminary (see fig. 1a) and developed phases (see fig. 1b) of a simulated construction project. It is imagined as a new construction of a residential building in a city environment characterized by different constraints in order to cover a wide range of construction site planning issues.

Figure 1: Screenshots of the project simulator for preliminary (a) and developed (b) pre-design phases

The preliminary pre-design phase starts with the project contextualization that consists primarily in the identification and evaluation of the constraints of the surrounding area. As showed in figure 1a, the first identification of the constraint is a specific color that shows what type of restriction characterize an object in the model. Thanks to some settings and parameters inserted in the template is possible to select the constraint type [11] simply flagging a property of the object. It means that, once flagged, that particular object take the color and, consequently, the properties (e.g. risk evaluation) of the chosen constraint type. So the high building and streetlights are flagged as *aerial restrictions* (pink), trees and houses near the construction site are identified as *surface constraints* (blue) while a school on the left represents an *interference with other activities* (fuchsia). After the definition of the constraints and the evaluation their impact on construction site (e.g. extra time and cost for tree cutting or plants relocation), the site designer have to start with the technological *Functional-Spatial* and *Technological-Plant* design. In this preliminary phase, in which the building design is in draft phase, he starts to identify the first needs of the construction site in term of site technical elements to put in place. For this phase as well as color characterization, the template contains also a library of volumes loaded in the model in order to have at disposal each type of feature to cover the need to be satisfied during construction. As an example, figure 1a shows that the first need is a division between the construction site and the surrounding area. In this preliminary phase it's only identified with a green solid since it has the task to show a need of a physical subdivision. In the next phase it will become a fence with specific characteristics given by the particular context and project issues. In the same way a red solid appears around the draft shape of the building that shows the need of a temporary structure. Orange and yellow identify, instead, the needs in term of infrastructure in construction site area (vehicle paths and storage areas). At the end of preliminary design the output is a model (coordinated with the draft of the building model) that shows all the future needs to satisfy in term of context criticalities and site system. Figure 1b shows the evolution of the preliminary design in the developed design. In this phase the building model develops from a draft volume to a more detailed object made on technical elements. The amount of information added permits to face the needs stated in the preliminary phase. The developed phase consist primarily in the translation of these needs in specific requirements useful for their satisfaction. So the need of a division between the street and the site is satisfied by a blind fence.

In the same way the need of a temporary structure is satisfied by the presence of a scaffold. Is visible how the template of the developed phase contains a library of proper site elements rather than simple volumes. Step by step, in the developed phase the CoSIM designer analyzes hence the single need of construction site (identified by volumes) and satisfy it by choosing the right site solution (identified by site elements).

4. Practice on a case study

In order to assess the effectiveness of the created templates, our task group tested them on a real case study. It consists of a demolition of a building located in a city centre environment and some intervention on the neighbouring structures. The choice of this intervention as a case study follows the aim to evaluate how the template can improve, in particular in terms of design time, the modelling of a proper CoSIM for an intervention. In fact, the chosen intervention was developed in another step of the research [10] without template and it is thus possible to make a comparison.

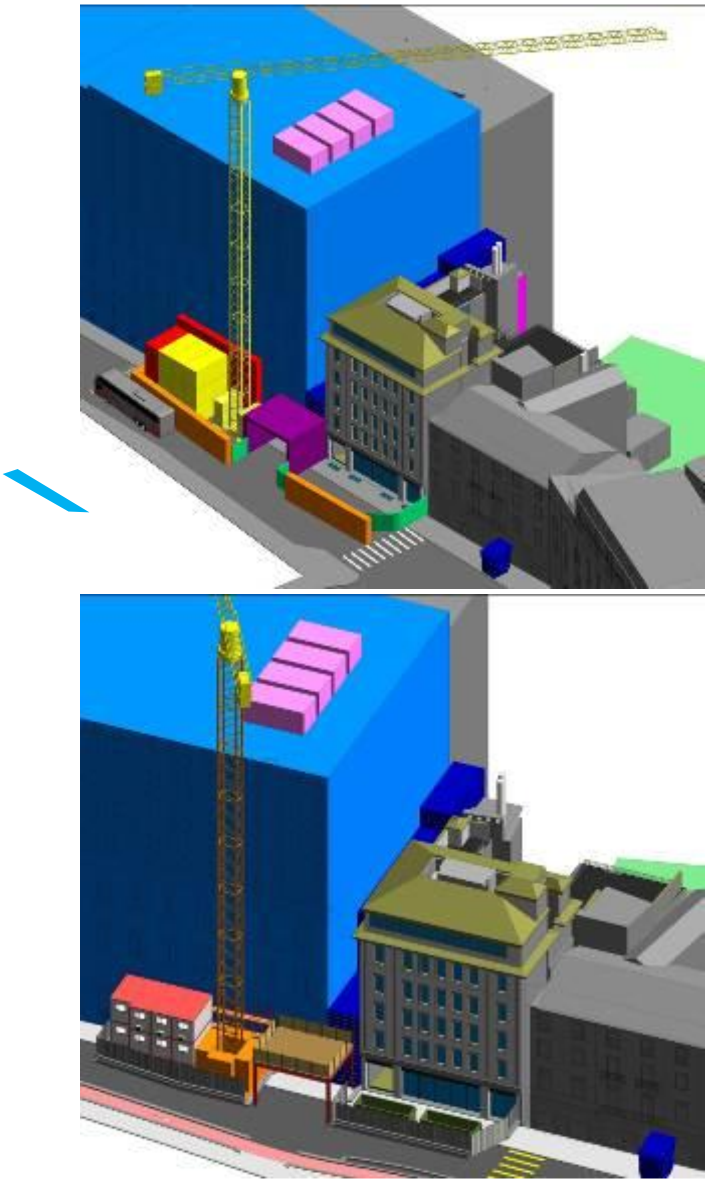

Figure 2: Screenshots of the case study for preliminary (a) and developed (b) pre-design phases

Figure 2 shows the development, from preliminary to developed phase, of the site layout for the first phase of the construction site before scaffolding mounting. The approach used is the same of the project simulator and the same design steps have been applied. First of all the context analysis underline the presence of the theatre (blue) and its indoor loading area for trucks (dark blue). Furthermore, air-handling units (Pink) on the theatre roof represent aerial restrictions to be taken into account during the choice of the crane. As visible the construction site layout follows the need to have an area in front of the building to be demolished as working area (the pedestrian path inside the fence will be covered by scaffolding) and storage of rubbles (light blue). The other area has been designed for logistic purposes and contains the crane and offices and services sheds (yellow). These areas are connected by an elevated working platform (purple) that permits to link the construction site areas without affecting truck entrance to the loading area of the theatre. As in the simulator, the red volumes represent the temporary structures able to connect the different floor of the sheds and the logistic area with the platform. Construction site areas are obviously bordered by a physical delimitation (orange) that needs to be opened in some parts to permits the access of construction site vehicles (green). Table 2 summarize how all the underlined needs have been satisfied in developed phase.

Table 2. Needs underlined in preliminary phase and solution provided in developed phase

Need underlined in preliminary phase	Technical solution for the satisfaction of the need
Strong delimitation between site and street (orange)	New jersey and steel panel fence
Delimitation that can be opened for truck entrance (green)	Site gates and modular steel fences
Logistic area with offices and services (yellow)	Pre-fabricated sheds on three floors
Elevated working platform and portal (purple)	Metal carpentry
Temporary structures (red)	Sheds with stairs and scaffolding
Rubbles storage area (light blue)	Storage containers

5. Discussion and Conclusion

As said the choice of this particular case study permits to evaluate the difference between modelling without pre-determined settings and modelling with these settings ready in a template. Therefore, in this case study the main design choices were made before the model, so the comparison takes into account in particular modelling efficiency. Frst of all is important to take into account the efficiency of the model in terms of design issue. The use of a template permits, in fact, to have at disposal an amount of information (for example the risk analysis related to a particular constraint) otherwise to be inserted manually. This characteristic of the template permits certainly to reduce design errors and forgetfulness. Another strong point is the facility to determinate and shoe a construction site need in a preliminary phase. In fact the preliminary CoSIM template is characterized by a series of volume in which site designer can flag the need choosing from a pre-determined list. This things, permits not only to be fast in preliminary modelling but to have an efficient starting point for the developed phase. In fact the library of construction site elements is set according to the need that they have to satisfy and the choice results immediate. In fact, although the template is different, the preliminary model can be imported in the developed template in order to have the exact starting point for developed design. The assessment of the efficiency of the template use in designing and modelling construction site took into account also the time consumed in modelling with very interesting results. In fact pre-determined modelling settings made the modelling process faster than before with a great satisfaction of the users. This efficiency has been found also in deliverable production thanks to the automation in information extrapolation and pre-determined types of graphical views. Although the results of the field test are extremely satisfying, some problems occurred in the use of a template due, in particular to the changing conditions of each construction site that don't permits to always follow pre-determined settings. The next step of the research will be so the refinement of the settings in order to fit as much as possible a large number of construction site possibilities. Another future step of the research will be obviously the test of the method with other software. In fact, although the template requirements aim to fit to the use of all software we see that each of them has some particular settings that need to be studied deep in order to adapt it to the defined requirements. In particular the procedures to reach the goal are different from software to software since each one has its specific functionalities. Despite of this the filed test encourage the task group to continue in this research in order to spread as much as possible CoSIM method and realize the aim of raise construction site planning to a clear designe discipline to be faced since the first phases of each project.

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Integrating BIM and Web Map Service (WMS) for Green Building Certification

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Abstract

LEED (Leadership in Energy and Environmental Design) is one of the most popular and globally recognized green building standards. In LEED, evaluating the sustainable effects of site location and transportation to the ecosystem and human life is a critical and difficult task. Credits regarding these matters require experience, time, labor, and manual calculations. In recent years, many studies have been conducted to enhance the application of Building Information Modeling (BIM) in the LEED certification. However, the application of BIM to LEED's site location and transportation analysis is usually considered impractical due to the lack of a powerful map application in present BIM products. The aim of this research is to develop a framework for the integration of BIM and Web Map Service (WMS) technologies for LEED's location and transportation analysis. Using Autodesk Revit API and Google Maps API as the development tools, this research converts the integration model into the LEED-BIM plugin in Autodesk Revit to streamline the certification process of site location and transportation analysis in LEED.

Keywords: LEED, BIM, Green Building certification, Building Information Modeling

1. Introduction

In recent years, Green Buildings have been a new trend of the construction industry to promote the eco-friendly design and effective energy consumption. More and more countries have developed their own Green Building certification systems, such as LEED in the U.S, CASBEE in Japan, BREEAM in the U.K, EEWH in Taiwan... to certify buildings in terms of "green" level. LEED (Leadership in Energy and Environmental Design) developed by the US Green Building Council (USGBC) has become one of the most popular certification systems for Green Buildings in the world [1].

Project location and transportation are the critical components of a green building project. A building in developed land or near dense residential areas can make more intensive use of existing infrastructure, increase development density, and conserve construction material and land resources for future use. A building near essential services such as banks, parks, doctor's offices, schools and restaurants… can help reducing the use of vehicles, time for parking and increase levels of physical activities, which can improve occupants' health. In regards to project transportation, it can help reduce CO2 emission as well as improve resident's health. Convenient access to bus or rail stations can promote the use of public transportation means, hence reduce vehicles' gas use, pollution and optimize the use of the existing transportation infrastructure. In addition, it can help reduce traffic congestion, noise pollution and improve resident' health by promoting physical activities such as walking or bicycling.

In LEED 2009, project location analyses are included in credits SSc2 and SSc4.1 in the Sustainable Sites category, which is the second biggest category after Energy and Atmosphere. Credits SSc2 and SSc4.1 has totally 4 options (for projects inside the U.S) as shown in the following table:

Table 22. Sustainable Sites Credit SSc2 and SSc4.1 (LEED NC 2009)

Credits	Intents	Options	LEED Pts
Credit SSc2: Development Density and Community Connectivity	To channel development to urban areas with existing infrastructure, protect greenfields, and preserve habitat and natural resources.	Option 1: Development Density	5 points
		Option 2: Community Connectivity	
Credit SSc4.1: Alternative Transportation - Public Transportation	To reduce pollution and land development impacts from automobile use.	Option 1: Rail station, Bus rapid transit station & ferry terminal Proximity	6 points
		Option 2: Bus stop Proximity	

Nowadays, BIM (Building Information Modeling) is widely used in LEED analyses, such as energy consumption, lighting, and sustainable materials…. Project site location information is usually included in most BIM software; for example in Autodesk Revit, it is included in Project Location under Manage tab. However, due to the complexity of the LEED calculation, architects and designers usually analyze LEED's site location manually.

To calculate LEED results in LEED SSc2 and SSc4.1 credits, designers and architects manually extract the project information (such as project locations, building areas, site area…) from project CAD drawings or BIM model. The map information of project site, including surrounding buildings, traffics, and local services has to be obtained from either paper maps or online mapping such as Google Maps. Moreover, it also requires the use of graphic software such as Adobe Photoshop to illustrate the map image and local area for LEED submission documents. This manual process requires a lot of time and labor, as well as skill to prepare document submission.

Web-Map Service (WMS) is the process of using the web interface to request map images delivered by a map server using geographical information systems (GIS) database [2]. It has many advance features over traditional maps by providing free online access in a browser application to maps with data associated with roads and traffics. With its strength and flexibility, Web-mapping service is a potential tool to support the map-related analysis in LEED Sustainable Sites credits.

There isn't any comprehensive software that allows users to calculate LEED SSc2 and SSc4.1 score and access by themselves. With the help of BIM and the web-mapping services such as Google Maps, the calculation process can be much faster and more accurate, thus can save significant cost and time.

2. Literature review

Studies on the integration of BIM in to Green Building analysis have been conducted to find out the experiences of the application of BIM in Green Building analyses. Krygiel et al. [3] summarized several case studies with successful implementation of BIM in LEED® and other green projects. In his study, an in-depth analysis of BIM application was conducted in various building systems including building envelopes, water harvesting, energy modeling, renewable energy and sustainable materials. However, site location were not a subject of BIM application in his study. Wu et al. [4] revealed that Sustainable Sites was not considered not having high level of BIM application compared to other categories in LEED [4]. Azhar et al. [5] presents a conceptual framework to establish the relationship between BIM-based sustainability analyses and the LEED® certification process.

Regarding site location and transportation analyses in LEED, studies also indicate that BIM has very low capability of LEED application. Unlike building performance characteristics such as lighting, thermal, energy consumption, etc.…that may potentially use BIM analyses, location and transportation has fewer direct connection with BIM software. In the survey conducted by Bynum et al. [6], most of the responders still regarded the Sustainable Sites category to have lower capability of BIM application than other categories. Azhar et al. [5] and Wong and Kuan [7] also discuss about the application of BIM in Hong Kong's BEAM-Plus Green Building certification, which was also developed based on the LEED standard. While his study concluded that 26 BEAM-Plus credits could be assisted by BIM, only 4 out of 17 credits in Site Aspect category (identical to LEED's Sustainable Sites) can be achieved by BIM. Credit SS2 Local Transport (identical to LEED's SSc4.1) and SA3 Neighborhood Amenities (identical to LEED's SSc2) are marked as not applicable to be achieved by using BIM. In conclusion, construction professionals are exploring the application of BIM in Green Building certification analysis. However, due to the missing map and calculation tools in BIM software, location and transportation analyses are impractical using BIM solutions.

3. Research objectives

The focus of this study is on the Location and Transportation analysis related to credits SSc2 and SSc4.1 of LEED for New Construction v2009. Autodesk Revit (BIM software) and Google Maps (WMS) are adopted in this study due to their popularity. Plugins for Autodesk Revit will be developed to help with credits SSc2 and SSc4.1 in Location and Transportation analysis. The plugins will automatically calculate SSc2 and SSc4.1 points (Note: These two credits are the major ones in LEED's Sustainable Sites (SS) category, accounting for 11 out of 26 points in SS), help prepare documents for LEED submittal, export proof map images with all required information marked on them, and generate an Excel file containing all location-related data. With the plugins, no manual switching between software and manual calculation of LEED points are needed.

4. Research methodology

The C# programming language together with Autodesk Revit API and Google Maps API are used for the integration of BIM, WMS and green building (GB) standards (Figure 1).

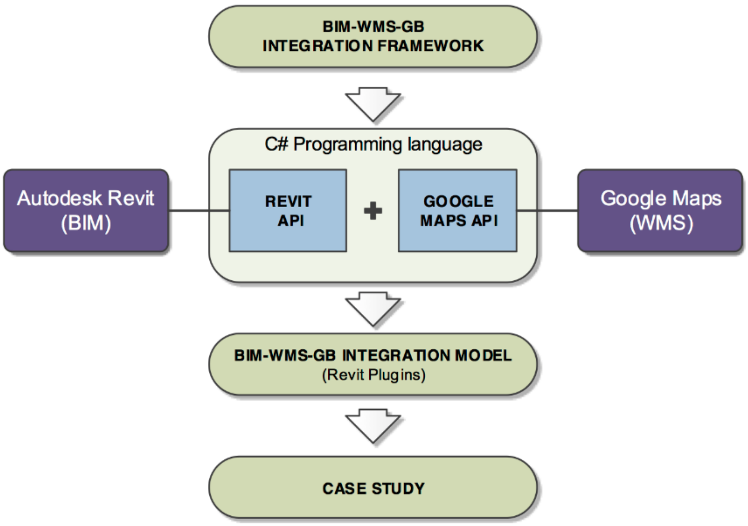


Figure 29. Flow of BIM-WMS-GB integration

The integration model includes 3 modules (figure 2):

- **BIM information module:** Extracts project information (location longitude/latitude, site area, building area…) from BIM model and synchronizes location information between UI and BIM model.
- **Web Map Service module:** Gets maps data from GIS server of multiple providers (Google, Bing, Yahoo…), and shows maps with buildings, traffic, local services...in the map interface. The module also draws markers, layers (density radius, services radius, route…), and exports Maps image for submission.
- **Green Building module (LEED):** Incorporates green building certification (LEED) requirements, formula and automatically calculate and show calculation results. The module also help export Excel data table for submission.

Through the integration UI, LEED results can be automatically calculated and shown on the UI to help designers and architect to have a good assessment of the Green Building location.

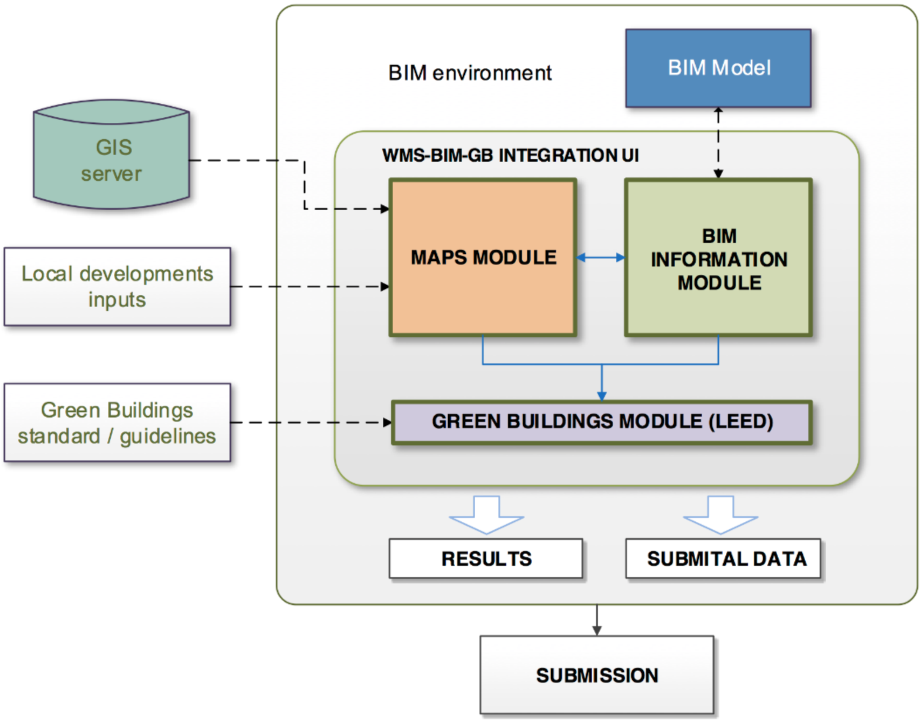


Figure 30. BIM-WMS-LEED integration framework

5. Integration model demonstration

5.1. *SSc2 credit – option 1:*

This option requires the project building to be constructed or renovated on a previously developed site and in a community with a minimum density of 60,000SF/acre [8]. The integration model can get the project location information from Revit model and show it on the map interface. The project Gross area and Site area can be obtained automatically through Revit Gross Area schedule and Site's Property Line area. The density circle is drawn with the radius calculated by the formula:

$$\text{Density Radius (lf)} = 3 \times \sqrt{\left[\text{Site Area (acres)} \times 43{,}560\ \text{(sf/acre)}\right]}$$

User can mark different building locations on map based and enter its site area and gross area. Development Density is calculated by the formula:

$$\text{Development Density (sf/acre)} = \frac{\text{Gross Building Area (sf)}}{\text{Site Area (acres)}}$$

If Development Density of the area within the circle >= 60,000 then the credits is obtained. LEED result is automatically shown on the interface.

The following figure demonstrates the user interface of LEED SSc2 – option 1 location analysis in Autodesk Revit:

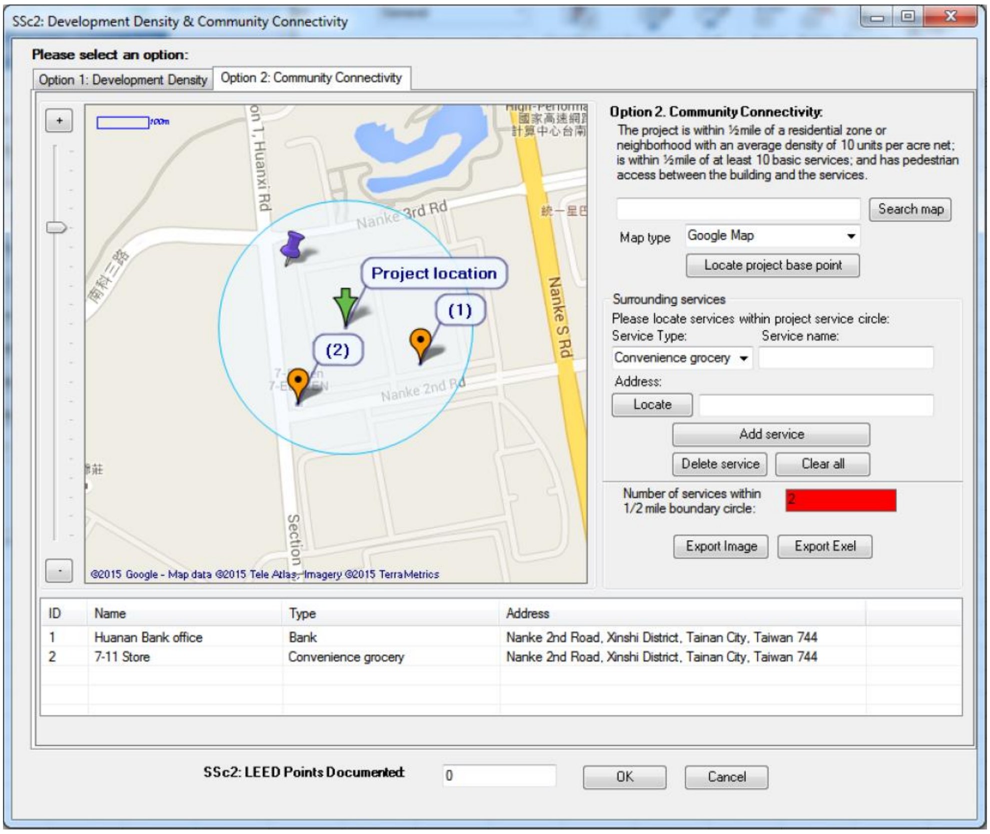


Figure 31. BIM integration model in LEED credit SSc2 – option 1: Development density

5.2. *SSc2 credit – option 2:*

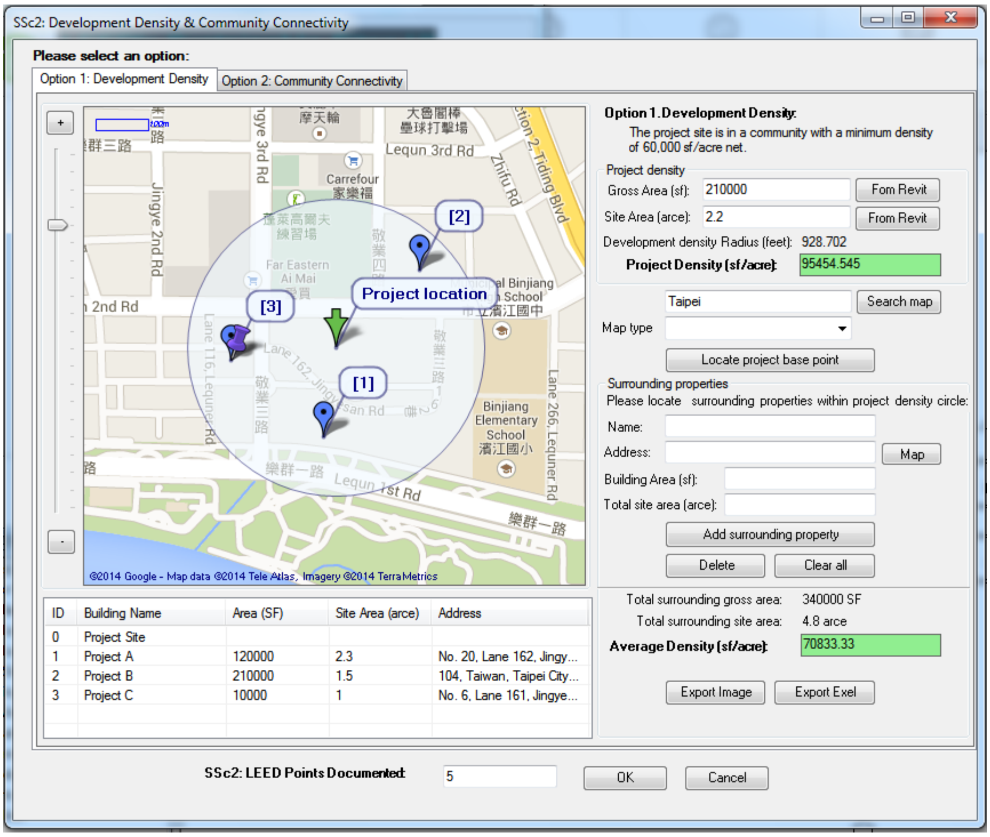
This option requires the project building to be constructed or renovated on a previously developed site within half a mile of at least 10 basic services with pedestrian access between the building and the services. The density circle is generated by the WMS module, with the density radius fixed at half a mile, as specified in LEED.

$$\mathrm{SR} = 0.5\ (miles)$$

Combining the map and the generated density circle, the user can input each of the surrounding services, such as school, laundry, etc., by placing a marker on the map. If Number of Services >= 10, then LEED points are obtained.

The following figure demonstrates the user interface of LEED SSc2 – option 2 location analysis in Autodesk Revit:

Figure 32. SSc2 Option 2 user interface



6. Conclusions and recommendations

Green building and BIM are rapidly transforming the design and construction industry in the world. However, application of BIM in LEED certification in general, and location analysis in particular, is currently still in its infancy. In this study, the system is developed through integrating BIM and Web-Mapping Service such as Google Map in LEED location analysis in order to simplify and shorten the process of green building planning schedule.

Currently, most countries are promoting the use of new technology in sustainable construction. If we can use the BIM technology efficiently in LEED certification, which information will be automatically reprocessed without additional manual calculation or using other methods, it can reduce costs of calculation and enhance the rates of green building application in the world.

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Geospatial Data Capture for BIM in Retrofit Projects - A Viable Option for Small Practices in Northern Ireland?

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Abstract

Within Northern Ireland, and the UK in general, building retrofit is an area of work undertaken by many small scale architectural technology, architectural and surveying practices. The methods, techniques and technology used for undertaking such work have remained largely unchanged over the years, with labour intensive measured surveys used in conjunction with hand sketching to capture existing asset layout and information. There are problems with traditional survey techniques, with data capture time consuming, and the quality of the information largely dependent on the skill and experience of the surveyor. There can also be issues with communication, interpretation of information, and human error. The emergence of Building Information Modelling (BIM) and associated scanning and point cloud technologies has the potential to transform the data capture process, improve accuracy, and enhance the general delivery of retrofit projects. However, at present, there appears to be reluctance by industry to embrace such processes for small to medium sized projects, believing BIM and associated technologies are not adaptable or affordable for this size of project budget. This paper sets out to test the above hypothesis by presenting the findings of a work in progress study comparing modern 3D data capture and modelling with traditional surveying approaches for a small to medium sized retrofit project. The research methodology employed was a case study analysis. The results of the study showed undoubted benefits of the modern data capture approach, in terms of speed of capture, accuracy and potential use of the model for additional building analysis, but also highlighted challenges in terms of costs, file size and experience in the use of the hardware for data collection and authoring.

Keywords: BIM, Laser Scanning, Retrofit

1. Introduction and Literature Review

Recently within the United Kingdom (UK) there has been a lot of discussion surrounding the retrofit of buildings. There are a number of possible reasons for interest in this area. From a building owners perspective, such reasons include the desire to reduce heating costs by having better insulated dwellings, and the economic downturn resulting in many upgrading rather then purchasing new properties. From a government perspective, the interest may be more to do with the targets set in the 2008 Climate Change Act [1].

A publication produced by The Department of Energy and Climate Change [2, 2011, p.5), highlighted the requirement for the building stock to play an important part in helping to reduce emissions over the coming years:

"In 2009, 37% of UK emissions were produced from heating and powering homes and buildings. By 2050, all buildings will need to have an emissions footprint close to zero. Buildings will need to become better insulated, use more energy-efficient products and obtain their heating from low carbon sources."

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Such targets are ambitious, especially considering suggestions back in 2007 that approximately 80% of the houses that will be around in 2050 had already been constructed [3, p.6]. The process of retrofitting buildings on this scale is a challenge, the extent of which was highlighted in the foreword to a 2011 report by the Centre for Low Carbon Futures [4, p.5]:

"If we are to hit our national carbon reduction target of 80% by 2050, almost every building in the country will need a low energy makeover. That means we have to improve nearly one building every minute, and we have to get the interventions right, first time. That is a challenge."

Within the UK, the devolved administrations have their own policies are targets. Focusing on Northern Ireland (NI), in the 2011-15 Programme for Government, the NI Executive outlined their own objective of working towards reducing, "*greenhouse gas emissions by at least 35% on 1990 levels by 2025*" [5, p.9]. The potential for the built environment sector to play a big part in carbon and greenhouse reductions becomes apparent when analysing the makeup of the dwelling stock, with 2011 figures showing 60.4% of which was constructed pre 1980 [6, p.22]. Therefore, with the majority of existing dwellings in this older age-bracket, retrofitting and generally improving their standard, where viable from a structural and cost perspective, is essential in helping to achieve the targets set by the Executive and improving the quality of the building stock, thus enhancing the comfort of occupants.

For retrofit to take place on such a scale, it is important that new methods of delivering projects in an efficient manner are investigated, and in a way that takes a more holistic view of building energy use. A possible way of doing this is through the use of Building Information Modeling (BIM), associated technologies and working techniques. Thanks to the introduction of mandates and policies, BIM is beginning to be used for a wide range of construction and infrastructure projects. However, these projects are mostly new build and have been undertaken by the larger firms. There appears to be a general lack of awareness of the potential for BIM, and associated working techniques, to assist smaller practices with the design and delivery of a range of projects, including retrofit.

Advances in technology and software means that laser scanning is now a feasible way of capturing highly accurate data for a building. This data can be brought into a range of software programmes for the purposes of design and analysis in a three dimensional environment. As outlined by Cousins [7, 2014, p.28], "*The latest 3D laser scanners are capable of capturing geometric data across large surfaces to accuracies of +/- 3mm and at speeds of up to a million points per second…*". This is of particular importance, as in implementing BIM for retrofit projects Ghosh et al. [8, 2015] highlight, "*proper capture of existing conditions becomes critical*." The use of such technology is in sharp contrast to traditional survey methods used for retrofit projects. In most cases, the process would begin with a visit to the building to undertake a measured survey, usually requiring two people to capture all relevant information in a sufficient level of detail to allow a two-dimensional plan and elevations to be drawn. In many cases, once the survey information is analysed, it may become apparent that a critical dimension has been missed or an important photo is missing. However, whilst the technology has the potential to improve the process, this must be weighed up against potential barriers, including; the knowledge required to use such technology, the availability of the hardware and software, the cost in undertaking the survey and the ability to use the information captured.

Within NI, it could be argued that the majority of architectural and surveying firms involved in retrofit projects would fall under the definition of a micro-business, outlined by Rhodes [9, 2015, p.5] as having no more than 9 employees. Even though NI has its own BIM policy [see 10, 2015, p.12], anecdotal evidence would suggest that this will only affect a relatively small group of said micro-businesses. The majority of such firms in the architectural and surveying sectors have simply failed to engage with BIM as they either feel it isn't relevant to their business model, believe that the techniques are unaffordable in smaller projects, or are perhaps unaware of the potential benefits to be derived from its implementation. As such, the majority have had no first hand experience of BIM or witnessed its potential to transform traditional approaches to project delivery, including retrofit projects, as previously outlined.

2. Methodology

With a lack of BIM knowledge amongst small-scale practices in NI, it is important that examples are provided and knowledge shared to demonstrate how advancements in technology and working methods could potentially be beneficial. For this paper a case study approach was selected which focuses on participant observation. Yin [11], describes participant observation as, "*the mode of data collection whereby a case study researcher becomes involved in the activities of the case being studied*." For this study it was considered that this method would be the most appropriate, as it allows the researchers to experience at first hand, the challenges faced during information capture and the modeling process, and how such challenges were overcome. This allows for a fuller understanding of the study and the ability to provide a coherent review of the work undertaken.

The overarching aim of this work is to evaluate the cost, time and accuracy of the information, drawing conclusions on the potential of BIM and associated processes for the delivery of such projects. However, as this is a work in progress paper, it will focus more specifically on the data capture technique, converting this for use in the BIM authoring tool and the creation of the model of the existing building. The process described will be compared to more traditional survey techniques, using the professional experience of the authors for comparative purposes. Finally, the discussion and conclusion section will offer a critical analysis of the work undertaken. It is hoped that this study will help to demystify BIM technologies and their potential to be used on retrofit projects, and provide impartial information, allowing those smaller practices involved in building retrofit to analyse if this approach would add value and enhance project delivery.

3. Case Study

The building being analysed in this case study is a former fire station located in Omagh, County Tyrone, Northern Ireland (Figure 1). The now vacant building was constructed in the 1950’s and has been an important part of the history of the town for over half a century. For this project the fire station was selected for analysis as there are potential plans to convert it for commercial development. This provided a perfect opportunity for modern data capture and model creation techniques to be used to investigate the benefits for a retrofit project.

Figure 1. Omagh Fire Station

3.1. *Laser Scan Survey*

The laser scan survey was conducted over two half-day site visits using a Trimble TX5 scanner, with the survey data registered using Trimble Realworks software. The building’s external doors and windows had been boarded up and the electricity disconnected, representing a challenge for surveying purposes due to a lack of natural light. As laser scanning is not dependent on or influenced by light, it was possible to utilise portable units to provide priority lighting to main spaces during surveying. Smaller rooms, accessed off the larger spaces, could not be fully illuminated at the same time. However, optimal positioning of the units allowed sufficient lighting to partial areas of the secondary spaces, facilitating safe access to set up strategically chosen scan station locations. Using traditional surveying processes, it would have been necessary to carry out more frequent, time-consuming maneuvering of the portable lighting system to fully illuminate each space to be surveyed.

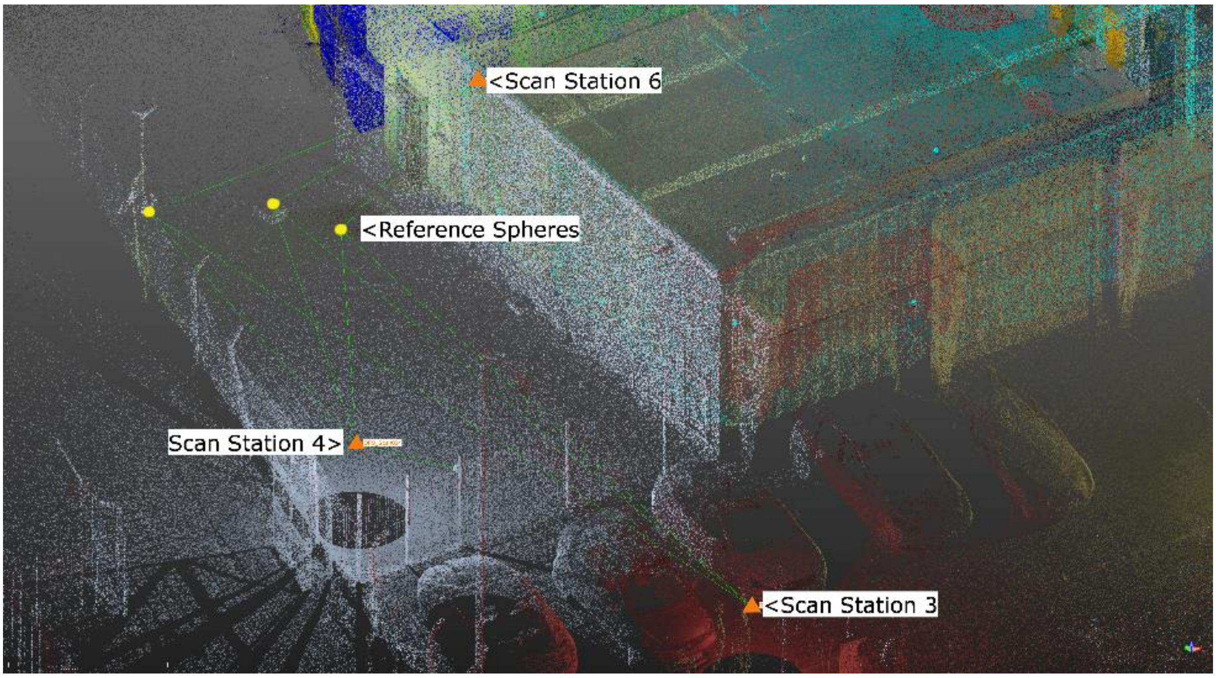
The image on the right (Figure 2), inside the side pedestrian door, is of the 3D point cloud which is initially captured in greyscale during the first rotation of the scanner. It is then coloured by Realworks during registration from a 360° panoramic camera image (shown on the left), captured during second rotation of the scanner. Note how the daylight through the door affects the camera image on the left but has no bearing, other than colouration, on the laser scanner image on the right which still captures points for the chain link perimeter fence outside.

Figure 2. Internal Scans

Where possible, the use of recurring strong planar surfaces in the survey environment were captured in adjacent scans to later allow the registration software to later join the individual scans into a shared coordinate system. Where this was not possible, for instance transferring the scanner around corners or through door openings, reference spheres were utilised in triplicate, for triangulation, to transfer the survey stations.

Figure 3, from Trimble Realworks, demonstrates how the survey was transferred from the exterior of the building into the interior. The Orange triangles and tags represent the scanner station locations and the Yellow circles the reference spheres. The green lines show the line of sight from each scan/station location to the reference sphere targets. Scans 3, 4 & 6 share the same 3 reference sphere targets thus their locations relative to each other can be triangulated. Station 6 is just inside the side pedestrian door where the images in Figure 2 were captured.

Figure 3. Transfer of Survey from Exterior to Interior



Although the laser scanner can capture spatial data accurately without a light source, additional images of the darker spaces were taken using a camera with a flash to provide a useful colour reference during the subsequent modelling process. Some dimensions were also captured throughout the survey with a tape measure. This is a useful check measure, allowing the eventual point cloud data to be corroborated as fit for purpose in the unlikely event that data becomes corrupted during the survey or registration processes.

During the second half-day survey, the additional spaces were captured. As the reference spheres had been moved since the first day, it was necessary to rescan the main space first before scanning the smaller spaces. By recapturing the main space, it was possible to coordinate with the previous scans. Based on assessment of the first day captured data, an additional scan was captured to the rear exterior of the building. This area had been captured on the first day at distance however, parts of the geometry had been just outside the range of the scanner thus was recaptured at a closer scale to strengthen the spatial data for this area.

Following completion of scanning, a full registration procedure using Trimble Realworks was carried out on the data to map all the individual scans to a shared coordinate system. The process of registering the scans can be quite complex and is not discussed in detail in this paper. Once the scan data was fully registered and the quality of the data checked, 3D point clouds were then extracted. Prior to handover for modelling use, the point cloud data was checked to ensure it was fit for purpose. This involved a visual assessment of the spatial layout of the point cloud data as being representative of the site and verification of 3D point cloud dimensions against the manual tape measure dimensions captured during the survey process.

3.2. *Model Creation*

The first stage in the process of model creation was for the scan data file to be imported into a suitable software platform, in this case Autodesk Recap, for assessing and editing. Using this software, the data was further 'cleaned' and edited to eliminate data (noise) which was not needed. During the scanning process a lot of unwanted data is usually captured, such as ground shadows, people and parked vehicles. These elements are usually deleted to make the file size more manageable. The second stage was to export the file from Autodesk Recap and import into the actual modelling software, in this case Autodesk Revit. Elevation levels and grid lines were created to aid the modelling, with elevation markers placed to correspond with the relevant heights within the scan data, such as finished floor levels and roof eaves and ridge. The scan data was essentially used as a reference for the creation of the model (Figure 3). Bespoke views, using the view extents and view range features within Revit, were used to identify sizes of building elements such as wall thickness and heights, and stair tread depth and riser height. These same features were used to locate the position of doors, windows and stairs, and generally allow the main structural and component aspects of the model to be created.

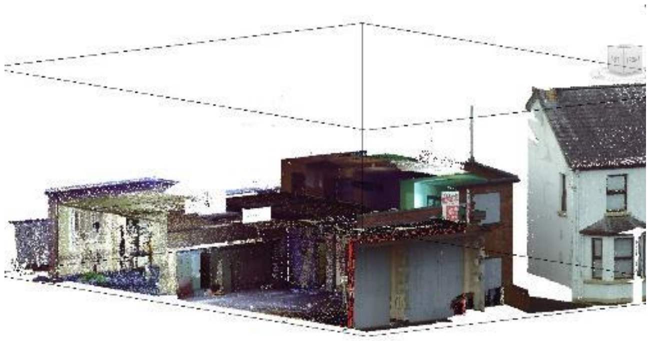


Figure 3. Cut-Away View of Point Cloud

Three separate models were created, an architectural model, a structural model and an MEP model. These were then federated together once complete. The reason for the creation of three separate models is for the purposes of clash detection. Although not necessary to convey the building layout, the individual models can be invaluable when undertaking retrofit work, with the building layout possibly being altered and new services and structural aspects potentially incorporated. Individual models facilitate clash detection, reducing conflicts when the work commences on site. The use of the 3D section box also proved useful in providing visual access to any part of the scan data and the model as it was produced. This tool not only reveals the basic elements and their dimensions, but also assists in ascertaining small details required for the production of bespoke Revit families. In this project bespoke families were created for two elements.

Once the scan data is accessible in the authoring software, the overall process of model creation is relatively straightforward for a proficient user. As all the information is available in the authoring tool, the model can be produced in a timely manner, albeit the building size, level of detail required, and the requirement for the creation of bespoke families all impact upon the overall model creation time. This process has a major advantage over traditional surveying techniques which rely on the skill and accuracy of those undertaking the survey, and their ability to communicate sketch plans, elevations, details and dimensions on paper. Within the process outlined above, the model can constantly be used as a reference as the practitioner can be confident with its level of accuracy. The same cannot be said with more traditional techniques, with the site possibly having to be repeatedly visited to capture data which has been overlooked or missed during the original survey.

As well as capturing the 'as built' asset for retrofit purposes, there are additional benefits to the laser scan process. Although outside the scope of this paper, it is useful to briefly highlight these benefits. The model created can be used to assist with any future work, such as proposed extensions. With the ability for the models to be 'phase specific', it is possible to phase the as-built asset as 'existing' and a future extension as 'new'. This is of benefit in terms of visually portraying any demolition work required, which has benefits in terms of quantification and demolition sequencing, thus also assisting with health and safety planning. The model can also be further used for the purposes of energy analysis. Revit is very comfortable and capable of interacting with software such as Green Building Studio which can produce analysis charts and reports on the model. In addition to this, factors such as wind analysis, solar studies and daylight analysis can also be analysed quite easily once the model has been created. Other outputs such as photo-realistic renders (Figure 4) can also be produced as well as the more traditional deliverables such as drawings and schedules. All of the above demonstrate how, once modelled, the asset can be used to aid intelligent design and analysis, something not easily replicated with the traditional process.

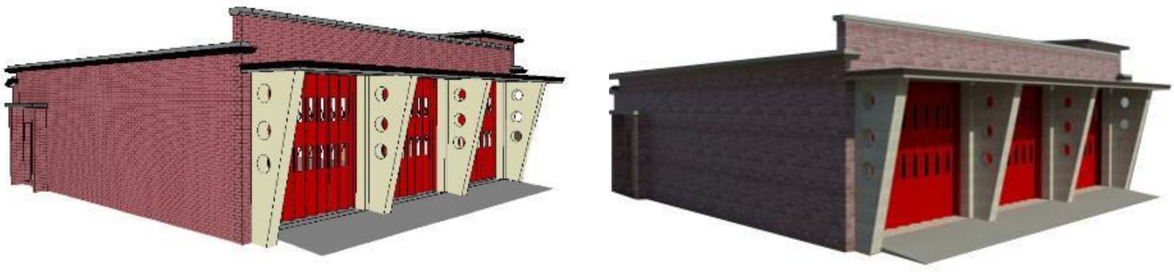


Figure 4. Work in Progress and Finished Rendered Revit Model

4. Discussion

Before a scan is undertaken for a retrofit project, or indeed any project, it is essential to have a detailed client brief, outlining what is expected from the scan and ultimately the model derived from it. This should be a two-way flow of information outlining what is required and what can be delivered, and requires an understanding of the scanning process and the authoring software. For instance, in a retrofit project, consideration needs to be given to the requirement for capturing a detailed model. Do bespoke families need to be produced with associated data attached, or will the building be gutted and thus a generic block model may be adequate, showing overall building layout with minimal internal content? Any critical aspects requiring capture, such as architectural details, should be specifically outlined as a deliverable. As the quality of any bespoke families produced will be dependent on the level of detail captured, the modeler should be briefing the surveyor as to his or her requirements. This is important; as such aspects can have a major impact on the project in terms of time involved, cost of modelling, and file size.

Another important consideration is on-site manual check measurements. These should always be obtained as they facilitate the checking of the model scale for accuracy. Inaccessible areas for the scanner should be compensated for by recording photographic images. It is important to remember that scanning is a line of sight process; therefore if the scanner cannot see the entity, the entity will not be captured or recorded. Until recently, this has been a problematic issue for inaccessible areas such as roofs on multi-storey buildings. However, thanks to the development of technology, laser scanning equipment can be mounted onto drones, which are able to fly to these inaccessible locations and record the scans assisted by stabilising technology. Where this is not possible, such as in built-up areas where the use of drones may not be permitted, a special tripod is available which can be used to extend the scanner up into ceiling voids, above domestic height eaves, or down into sub-ground systems. When undertaking the scan, especially for retrofit, specific building materials should be noted on site by the surveyor. This is particularly crucial if the façade of the building is to remain unaltered, and the model will be used for rendering purposes with photo-realistic images specified as a deliverable.

4.1. *Laser Scanning Compared to Traditional Surveying Techniques*

Probably the greatest single advantage of the laser scan process over traditional techniques is the speed of surveying and capturing data. Large buildings can be captured within hours and single days, whereas traditional surveys and manual measurement could take a lot longer for the same asset. A caveat with this is the issue of cost. The reason for this rapid capture of high quality data is due to the high specification and capability of the equipment used, and thus there is a cost associated with this. The approximate cost of buying a new entry level laser scanning is around £35,000, with a second hand scanner costing approximately £20,000. This is a huge outlay for any small practice, and is not a viable option for most. The value calculation needs to consider the initial outlay in terms of purchase, training and lost productivity when progressing through the initial learning curve. This should be compared against the time saved on site collecting data, on asset creation and the benefit of using the model for building analysis and better predicting future building performance. A more viable option for many small practices would be the option to hire a scanner for individual projects, the cost of which would be a lot more feasible, around £500 per day for scanner hire, and could be included as part of the fee proposal for the scheme in question. However, this would still require knowledge of the scanning process. For many practices, unless a clear pipeline of work is secured via some sort of contractual agreement, the most attractive option may be to procure these services from a specialist subcontractor. Once again, the cost could be built in as part of any fee proposal.

Obviously another major benefit of the process is the capture of a 3D model. Even if nothing else were to be done with the data, the asset has still been recorded at a specific point in time, potentially capturing every detail in three dimensions. It has been highlighted that such data capture is particularly beneficial to the insurance sector, should anything happen to the building, as it could be used to assess the current state of the building or asset. High detail data capture is also of particular benefit in conservation projects where such detail is critical, and also for capturing and recording buildings of historic importance. The capturing of laser scan data is of great benefit to the modeler, and allows an existing building to be modelled in a much easier fashion as opposed to trying to interpret two dimensional paper measurements in the traditional process. It should be noted that a specialist skill set is required in order to accurately capture the data and then process it for use in the Revit software platform. Anyone considering using this method must either have someone in their practice with these skills, be prepared to pay for relevant training and development time, or pay a specialist consultant to undertake these tasks. The aforementioned needs to be considered in addition to the cost of actually undertaking the scan. That said, technology and software is continually evolving and is likely to evolve further over the coming years to make the process more straightforward, leading to more efficient workflows. Already, huge progress is being made, with programmes able to identify elements within the data and automatically model these elements. For example, pipe work and ducting can be automatically recognised, selected, and automatically modeled in the software. This is not only possible for a single pipe, but for an entire run or system, thus eliminating hours of tedious modelling. This would suggest that some projects may be more suited for this process than others, depending on their complexity and the requirement to accurately capture internal services.

Although the process has many undoubted benefits, it is important to highlight the drawbacks to provided a balanced overview and allow individuals to make a considered decision on the use of such practices within their organisations. Laing et al. [12] highlight potential issues with scanning "*highly reflective surfaces*", and also when scanning in poor weather conditions such as rain, "*as the laser will detect water droplets, rather than the intended physical surface*". With greater detail being captured in the laser scans, large multi-gigabyte file sizes are common. Resultantly, the handling of these large files by workstations leads to increased performance demand and the requirement for greater RAM and graphic card specifications. Another point of note relates to buildings which have bespoke elements which have to be modelled as masses or individual families. This can be very labour intensive and add additional time and cost constraints which may not have been readily apparent at the outset of the project. That said, the finished model should have a much higher level of accuracy with this process than trying to capture such surface using traditional surveying techniques.

5. Conclusion

As outlined, this is a work in progress paper, concentrating on BIM and associated technologies for data capture, processing, and model creation in retrofit projects. This work forms part of a wider study, investigating the potential for such working methods to transform the delivery of retrofit projects for small practices in Northern Ireland. As such, conclusions will not be drawn until the project is complete. However, it is worth noting the main findings to date. Analysis would suggest that there is much to be gained from small scale practices adopting modern data capture techniques. Although the cost associated with purchasing laser scan equipment is a barrier, the potential to hire such equipment for individual retrofit projects or to procure the services required from specialist sub-contractors, means that it should be viable for many small practices. There is also the knowledge barrier, and ensuring individuals have the necessary skills to carry out data capture and/or use the information within BIM authoring tools. However, the ability to create a highly accurate 'as built' virtual asset model from the laser scan data is just the starting point. The real value is in the use of this model for the purposes of energy analysis and clash detection, and for future extensions or alterations. Focusing on energy analysis, the importance of this area has been highlighted in the review of literature. The possibility of using asset models to analyse and simulate energy use based on the retrofit proposals is an area of huge potential. It facilitates the virtual analysis of design proposals until the optimum solution is found. This has the potential to be a 'game changer' for practices, regardless of size, and a way of assisting with the creation of a more efficient building stock.

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Field BIM and Supply Chain Management in Construction: an On-going Monitoring System

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Abstract

In spite of the growing implementation of Computer-aided technologies and Building Information Modeling (BIM) in AEC industry, building activities in construction sites are ineffectively monitored even now. Current formats of reporting and communicating the construction progress (e.g., textual progress reports, progress lines, and photographs) may not properly and quickly communicate the construction progress. In the proposed research the capability to communicate progress information right away and to share an Interactive Building Model (IBModel) are identified as the key components for successful management of the site and the supply chain network. This is carried out establishing the involved actors (Owner, Site Director, Site Safety Coordinator, Construction Companies and Suppliers) and setting them several options for the information management and visualization within the BIM environment. The monitoring system comes from the integration of the building and construction site model bestowing the visualization of site conditions on a set of graphical parametric rules, such as: chromatic visualization of building components referred to objects' completion percentage; thematic views, automatically extracted and updated, representing the real site conditions; and so forth. The monitoring system, supported by the BIM-based visualization model and managed in a Cloud computing seems to be one of the right directions for improving safety condition on one hand and site productivity and control on the other one.

Keywords: building information modeling; field BIM; monitoring system; site management and control; supply chain management

1. Introduction

In recent years, with the increasing level of competition in the AEC Industry, several research efforts have focused on the application of information technology (IT) as a way to improve the integration process of Construction Supply Chain Management (CSCM) [1]. Visual representation of the process can provide an effective tool for monitoring resources and construction process in the CSCM. At the same time, Building Information Modeling (BIM) has played a pivotal role in reforming the information flows in the construction supply chain. Extensive worldwide efforts have been undertaken to enhance different aspects of BIM implementation in various domains, including how to improve a collaborative work on the construction site. In fact, BIM enables information creation and reuse throughout the project life cycle and for that reason it also facilitates collaboration and provides a database platform for site management during its progression. This platform, when coordinated, integrated, and preserved properly, can be effectively used to support various operations.

This study proposes to integrate BIM and CSCM within an on-going site monitoring system. It is based on the implementation of a BIM-based information management and control system within a cloud environment for monitoring the progress of construction operations through the analysis of data coming from the construction site and collected by means of construction apps and mobile devices directly by the main construction actors: General Contractor, Subcontractors, Suppliers, Site Safety Coordinator and Site Director.

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The paper is structured as follow: Section 2 reviews three fields that are strictly connected with the proposed workflow; Section 3 explains the methodology which are tested in case study widely illustrated in Section 4; finally, Section 5 discusses results and future developments.

2. Background

From the end of the 1980s, the construction industry has seen the launch of a number of supply chain management

(SCM) initiatives which have been focused on four major roles of SCM in construction [2]: (a) Improving the interface between site activities and supply chain (b) Improving supply chain itself (c) Transferring activities from the site to the supply chain, (d) Integration of site and supply chain.

In this regards, the use of information technology (IT) is suggested to achieve better logistics processes, indeed, various IT applications have been used in the literature as a way to improve the integration process of CSCM [3]. These applications have harnessed the capabilities of IT to facilitate the mapping of time and cost resources and also transportation analysis and optimization models to improve logistics performance [4]. In the recent year the use of IT–based tools comes in the direction of BIM which combines the design and visualization capabilities with the rich parametric object provides tools for the integration of digital building models with construction site.

Concerning the integration of site and supply chain, traditionally project information is acquired during on-site inspections and data is recorded in paper-based documents to be shared with the supply chain [5]. On the other hand, mobile devices are becoming widely used on site in order to acquire and process data [6], to improve information management and to increase operational efficiency [7]. Currently, many construction applications are available for activities such as quality control and construction management [8]; some of these technologies can be effectively linked with BIM authoring platforms. Anyway, the full potential of mobile technologies implemented within a BIM Environment can be achieved only when the information obtained on site is effectively shared among project participants, supporting the decision-making process [9]. For instance, understanding the current status of a construction project is essential for a successful on-site management: mobile technologies could provide improved accessibility of project information to all the stakeholders and increased efficiency of information exchange. IT and interoperability, in fact, eliminate the need to manually copy data already recorded on site [10] by linking mobile devices with a shared database [9], the Building Information Model.

3. Methodology

The study aims to develop a collaborative CSCM Environment in order to achieve common development goals between actors, to share the same site progress information and to adopt the same approach to inform the supply chain on site in order to improve cooperation opportunities [2].

A Building Information Model (BIM), managed by authoring rules, parametric filtering rules and visualization settings, will be used to reach the goals listed below:

- Sharing the BIM, including site layout and safety plans, across the construction supply chain schema in order to make it robust when facing uncertainty;
- Updating and synchronizing the Building Information Model with data coming from different users and applications in order to effectively visualize updates according to construction processes and site changes;
- Synchronize the BIM with supply chain schema in terms of site users and construction operators by using BIM authoring rules;
- Manage the order information propagation informing the construction supply chain, in terms of direct suppliers and subcontractors;
- Visualize and manage the common usage of site organization in terms of main work spaces, site spaces and equipment (e.g. if a supplier need a crane to install components he can display its availability before entering in site, without coming in conflict with other users preventing delays and congestion using a truck mounted crane).

The integration between the on-going site monitoring system and the Building Information Model, which represents what the authors called the Interactive Building Model (IBModel), is structured in the following three work-steps.

3.1. *Modelling assumption*

The Building Information Model is structured in three main objects' categories:

- *OB_1) Building elements*: components of the design solutions that, according to monitoring aims, should be scheduled in construction activities. The optimal solution should be a 1:1 ratio have to be established between activities and simulated building objects; anyway, the granulometry of the BIM in terms of Level Of Detail (LOD) specifications should be assessed in the planning phase of the monitoring system, in a round table with the client, in order to define how many actors in the chain seem to be able to impact site and activities performance;

- *OB_2) Site facilities and work-spaces:* according to the arrangement of the site layout, the available site facilities across each construction stage should be given as models inputs. With regard to workspaces, the general process to identify their evolution pattern would be as follow: (a) identification of the construction activity that is required to build an individual construction object according to the Information model's granulometry identified in step 1; (b) determine the workspaces needed at all stages in the life cycle for the construction activity;
- *OB_3) Equipment*: in order to manage the use on site of equipment, their workspace are simulated both for static (e.g. scaffoldings) and dynamic ones (e.g. crane).

3.2. *Parametric filtering rules*

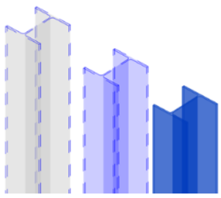
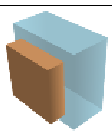
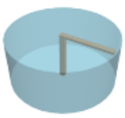
The Interactive Building Model (IBModel), which is the core of the proposed monitoring system, works through a list of parametric filtering rules which effect its synchronization and vitalization.

For each Objects' categories, listed in 3.1, their (1) monitoring parameters and (2) data set and filtering rules have been defined and linked to the objects visualization by using the (3) display patterns, which govern how the IBModel transfer the on-going monitoring to the users (Table 1).

3.3. *Responsibility assignment matrix*

After the Building Information Model is structured according to the logics in step 3.2, the BIM Monitoring Environment should be manage in terms of data monitoring and authoring tools. This is carried out using the *Responsibility Assignment Matrix* (RACI Matrix) which describes the participation by various roles in completing tasks or deliverables for the monitoring system. Four monitoring actions are covered: 'Add Information', 'Permission to view', 'Edit Information' and 'No action'.

Table 23. Objects' categories and parametric filtering rules

Object Category	Monitoring Parameters		Filtering rules	Display pattern
Building Elements (e.g.)	*Constructed by Sub-contractor or Supplier*		Name assignment	Type of Colour = X_n
	*Construction Percentage Progress* PP	To start	Number assignment (%) *PP = 0*	Colour Transparency = PP
		In construction	Number assignment (%) $1 \leq PP \leq 99$	Colour Transparency = PP Dashed line edge
		Ended	Number assignment (%) *PP = 100*	Type of Colour = X_n Opaque Colour = X_n
	Construction Progress Standby		Text assignment	Type of Colour Red Colour
Site facilities Workspaces (e.g.) 	*Used by Sub-contractor or Supplier*		If one	Type of Colour = X_n
			If more than one	Tag
			If Available	Continuous line edge
			If Not Available	Dashed line edge
Equipment (e.g.) 	*Used by Sub-contractor or Supplier*		If one	Type of Colour = X_n
			If more than one	Tag
			If Available	Continuous line edge
			If Not Available	Dashed line edge

Finally, figure 1 shows the architecture of the developed system.

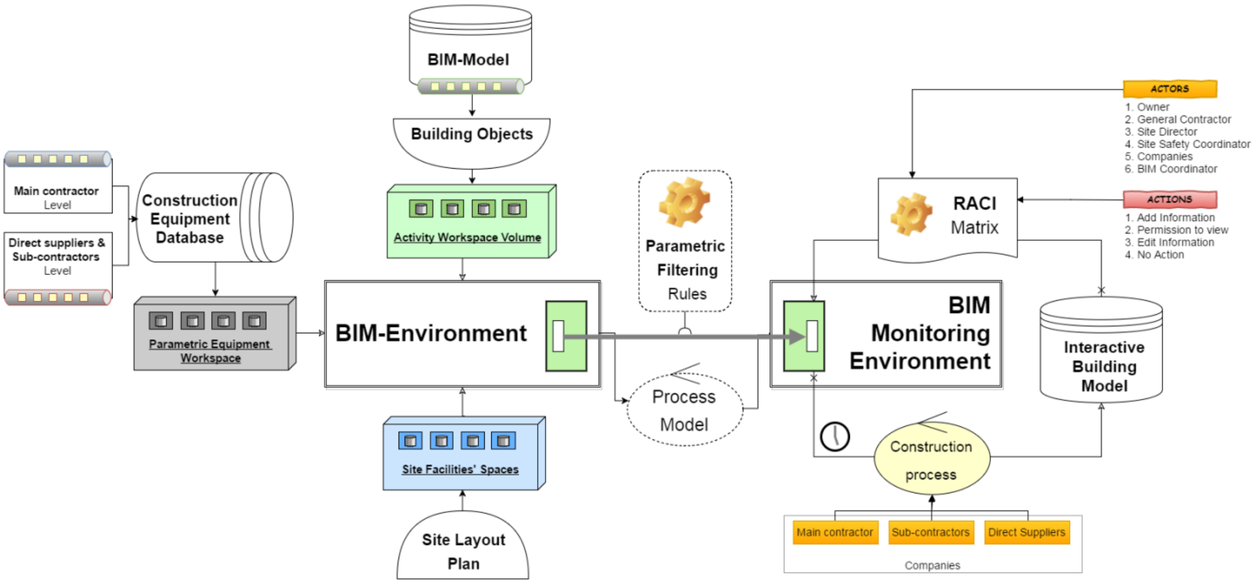


Figure 1 Process Map

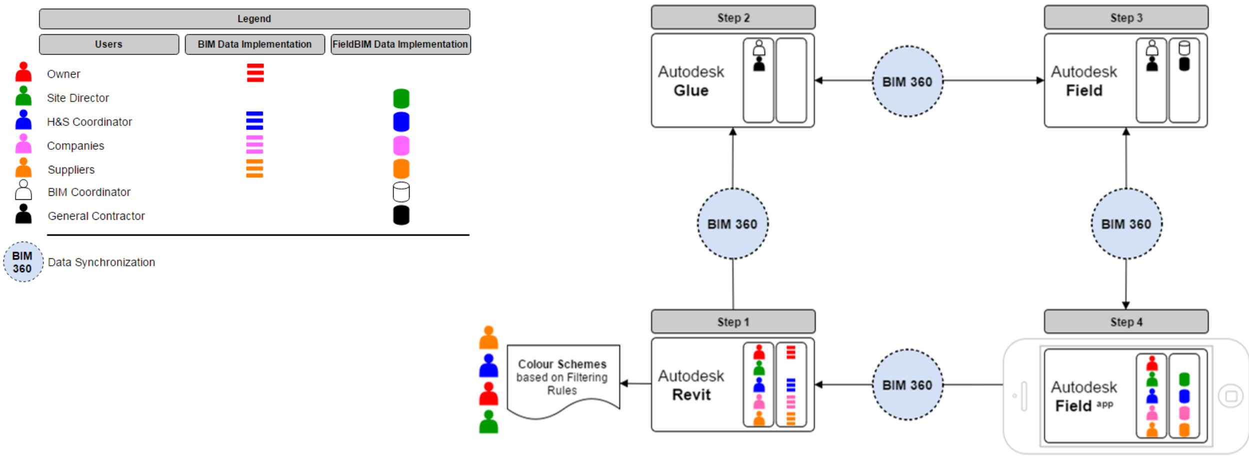
4. Methodology computation and case study

A preliminary implementation of the BIM and CSCM integration is described. The proposed methodology was tested simulating the workflow with experimental purposes, in collaboration with a medium-sized construction company and some of the M.Sc. students of Construction Management at the University of Brescia. The case study is a four-floor building containing offices and laboratories. The supporting structure is made of full-height precast columns and precast beams assembled in place, while the stair, the elevator core and the structural walls are in cast-in-place reinforced concrete. Exterior panels are reinforced concrete prefabricated elements.

4.1. *BIM Environment and Information Workflow*

In order to test the implementation of the proposed methodology, a BIM Environment was defined [10]. It consists in a BIM authoring platform and two construction apps connected to each other with a closed-BIM approach, based on the Autodesk BIM 360 cloud potentialities. Closed-BIM means that only native formats of a single software house were used [11]. Part of the proposed iterative BIM-to-Field BIM workflow (Figure 1) was tested, synchronizing Revit to BIM 360 Glue and BIM 360 Field. Glue and Field are BIM management and construction management products that combine desktop and mobile technologies with cloud-based collaboration [12]; these tools were used in order to enrich the BIM informative content with the monitoring information according to Table 1. The data flow was managed by using native formats (.dwf and .nwc), testing different interoperability scenarios. The process is structured in four steps (Figure 2): for each of them the *Responsibility assignment matrix* was defined in terms of users, roles, permissions to view, add and edit information. The proposed workflow is an iterative process, starting from the design phase in the BIM authoring platform, where geometric and non-geometric information related to the construction phase is embedded in the Building Information Model, including the construction site layout one. Other properties, such as monitoring parameters listed in Table 1, will be later included in Field BIM tools in order to support the supply chain management; these attributes will finally update the informative content of the Building Information Model with data coming from the construction site, creating a coherent and shared database. In the BIM authoring platform, parametric filtering rules are set in order to create thematic views automatically updatable for data visualization and communication. These views are customized according to the users involved in the process and having access to the Building Information Model.

Figure 2 Information management workflow between the design phase and the construction management one. Users, roles and their permissions to add, view and edit information are defined.



4.2. *Setting the Interactive Building Model (IBModel)*

The first step concerns the creation of the Building Information Model in Revit. Non-geometric properties were added for monitoring the construction phase, with a focus on construction progress and CSCM supported by an improved visualization and collaboration between project stakeholders and BIM users [13]. The actors involved in the construction phase were defined: owner, site director, site safety coordinator and construction companies (general contractor, subcontractors and suppliers). Each user was identified with a color that was also used in setting thematic views and color schemes to be updated with data coming from the construction site. Actors have different permissions to visualize, edit and add information within the model, filling BIM objects' attributes related to building elements, site facilities, workspaces and equipment. Examples of these attributes are identity data and spaces/equipment availability to the construction companies working on site. For instance, contractors could manage information about their subcontractors, suppliers and connected workers. The Site Safety Coordinator could define which working area can be used by contractors and suppliers in different construction phases and they could use this information to optimize their schedule. Moreover, identity data of construction companies and suppliers could be useful for the Site Director. At this point the proposed IBModel visualization shows its benefits.

Once the BIM template had been organized, the model was exported to Autodesk BIM 360 Glue via the add-in for the cloud environment, BIM 360. In Glue different models can be merged and coordinated. In this case, Glue was used as a necessary intermediate step for exporting the Building Information Model from Revit to the construction app Autodesk BIM 360 Field, where it can be managed with Field properties such as construction progress information. In this phase, the BIM coordinator and the General Contractor should be involved. The former should visualize and coordinate disciplinary Building Information Models, as well as oversee the information management workflow; the latter should manage the process according to construction procedures, defining stakeholders and responsibilities on site and mapping BIM objects properties following construction management and quality control criteria. Default construction properties in BIM 360 Field are *location*, *status*, *install date*, *purchase date*, *purchase order*, to name a few. Other custom properties were created assuming some possible IBModel uses: the WBS code and the "Construction Percentage Progress" were added for monitoring the construction phase. Moreover, checklists of quality control (QC) and safety management were digitalized.

The third step consists in synchronizing the BIM with the Field BIM app on mobile devices. Team members can update the construction properties and fill the QC and safety management checklists monitoring on-site activities. For example, the "Construction Percentage Progress" can be monitored and the relative parameter filled to be later synchronized with the model in Revit, where this data will be visualized and analyzed by the Site Director and the supply chain. The former will have to validate the construction progress; the latter could use this data in order to organize the material procurement and the building components' production.

Finally, Field properties are synchronized to the Revit model shared with Glue and integrated with Field [12]. The informative content of the Building Information Model is updated at the construction phase, including information about construction progresses and detected issues. In order to effectively visualize the information coming from the construction site, thematic views were set by means of parametric filtering rules. For example, multiple levels of transparency represent the progress of construction activities according to the rules described in the methodology Table 1. The thematic view related to a contractor's activities was set with the color defined at the beginning for this contractor (Figure 3) with different percentages of transparency representing different levels of construction progresses. In the proposed system, the contractor can define a "Construction Percentage Progress" between 1% and 99% in order to visualize the building object with the related color at different levels of transparency. Site Director has to validate the conclusion of the construction activity and the 100% of the construction progress. A filtering rule was set so the BIM object changes color if the related activities are 100%

completed (Figure 4). Any changing values for these parameters is synchronized and views are automatically updated depending on the filtering rules set.

5. Results and discussion

Preliminary results of an IBModel based on the Autodesk BIM 360 workflow have been described. The main aim was an improved information exchange during the construction phase, implementing construction apps and mobile devices into a BIM-to-Field BIM Environment. Anyway, a smoother and open workflow would be needed in order to effectively acquire and process data integrating BIM and CSCM. A customized BIM aware application should be developed to better support this integration and an improved collaboration between all the stakeholders involved.

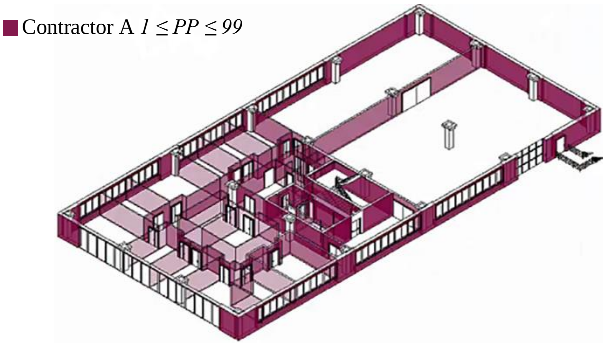


Figure 3 Model view for the visualization of the construction progress related to a specific contractor (construction percentage progress PP between 1% an 99%)

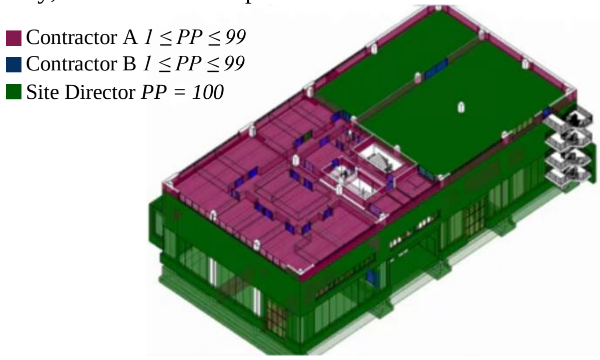


Figure 4 Model view to be used by the site director to validate the conclusion of construction activities and by the supply chain to monitor the construction progress

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Analyzing Design Workflow: An Agent-based Modeling Approach

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Abstract

Variability embedded in the architecture, engineering, and construction industry often results from inefficient planning strategies, sub-optimal levels of coordination, and poor flow of information and resources. This inherent variability disrupts workflow in design, results in longer cycle times, increased costs, and rework; thus undermining design, as well as, construction performance. This paper addresses design workflow at the intersection of the social and process aspects of the design phase. These aspects have been studied separately in previous research works, which prevented capturing a comprehensive and realistic understanding of the design process. Accordingly, this study develops a new approach to qualitatively and quantitatively model the exchange of information between design players and pave the way to assessing the impacts of Building Information Modeling and new project procurement strategies on improving design workflow. Agent-based modeling is used to dynamically represent the relationship between social interactions and the diffusion of information between individuals and teams. The study presents a novel design workflow management approach that bridges the gaps in previous studies as it focuses on team structures, interaction dynamics, and information diffusion.

Keywords: Design workflow, Agent-based Modeling, Building Information Modeling (BIM), Collaboration, Social Networks

1. Introduction

Design workflow can be defined as the flow of information, deliverables, specifications, and other design resources between the right people at the right time. Maintaining a smooth flow of design information is key to a value adding transformation of design input into the client's proposition. However, designers, planners, engineers, and constructors only focus on the transformation process, from input to output, ignoring what happens within the vague box of transformation. While poor flow of information and design errors plague the design process resulting in delays, increased cost, and compromised design quality, available literature address such issues without an in-depth study of inherent problems in design communication networks and behaviors. Traditional planning and management methods applied during design do not consider workflow or the drawbacks of variability. Variability embedded in the architecture, engineering, and construction (AEC) industry often results from inefficient planning strategies, sub-optimal levels of coordination, and poor flow of information and resources. This variability disrupts workflow, results in longer cycle times, increased costs, and rework; thus undermining design and construction performance [1, 2].

In fact, perceiving the design process as a flow of information rather than a rigid segmentation and sequencing of design tasks can lend itself to a better design management approach [3]. Such conceptualization is the foundation to finding ways to reduce the time information that is queued before it is used, minimize time spent on reworking design information to meet requirements, and avoid unnecessary overproduction of obsolete data. More importantly, this perspective of design as information flow is crucial for the integration and coordination of multidisciplinary information at a current time of increasing design complexity, sophisticated client needs, and a

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rapid proliferation of information from multiple geographically dispersed teams. With the presence of different project procurement approaches that call for more collaboration among project teams, and with the utilization of modern technologies, namely Building Information Modeling (BIM), the need to evaluate their impacts on design workflow and compare their performance to more traditional delivery approaches calls for a new perspective to better understand design workflow. Although defining what better design management entails and how workflow should ideally be, a practical analysis of workflow characteristics and the influence of human interactions that shape these workflows in the context of BIM-based design processes and collaborative deliveries have not been considered or examined.

In this regard, the design phase should be conceptualized as the intersection of a social organizational structure and the involved dynamics of information exchange. The integration of these segregate approaches remains absent resulting in incomprehensive analytical methods that fail to capture a realistic image of information flow within design networks. In this respect, this study first highlights some limitations in the current analytical methods and proposes a novel approach that uses agent-based simulation for modeling information flow within social network topologies of team coalitions. Potential implications of this approach are then introduced.

2. Gaps in existing methods for workflow analysis

Existing analytical methods tend to separate the topology of team interactions from the flow of information by focusing solely on design task transformation while neglecting the flow of design information, or by only considering the structural setup of involved individuals and ignoring information diffusion, or by analyzing information diffusion and ignoring team coalitions. Some gaps in the current body or research and practice are presented below:

- The role of information flow between designers is not broadly considered in research and the industry, which results in poor workflow practices. Informal surveys conducted with design teams revealed that negative iterations (rework) constitutes an approximate 50% of design time [4]. This rework can be a result of obsolete or missing information that was not promptly shared. In practice, individuals and teams work in isolation without realizing that information they are withholding is useful for other team members and the overall design requirements.
- The negative impacts of poor design workflow are not fully understood which limits the incorporation of flow into actual practice. Some studies have developed flow diagrams to qualitatively map the flow of design deliverables through different stages of the design process [5]. However, this flow has not been mapped across multi-disciplinary teams to highlight the interactions between trades with different design needs and outputs. Therefore, the impact of such multi-disciplinary relationships on information flow was not thoroughly assessed.
- The existing frameworks for the quantification of flow metrics are incomplete and insufficient, which makes it hard to measure performance on design projects. Measuring performance is an important step to assess design workflow and implement the required changes. A few studies were targeted towards measuring design information flow rates on projects by tracking database logs and showing trends of indices reflecting design workflow of [6]. While such studies provide important metrics to quantify information flow based on database, they neglect a critical controlling factor in the process of information flow: individual and team interactions. Social network structures and their impact on flow of design work and design quality are not taken into account when measuring information flow.
- The dynamics of information flow and interactions between design individuals are not considered when measuring design workflow. Some studies highlight the importance of realizing design and construction projects as social networks constituting design players and their communication [7]. Interesting studies develop a modeling method that links design tasks to the responsible people within a social network using network analysis [8], and also develop metrics of collaboration and team work and link them to the ability of information to reach people depending on their respective position in the hierarchical networks [9, 10]. Although these studies give insight into the integration of design activities and people involved, they do not model the exchange of design activity information as input and output deliverables, which prevents the realization of design workflow patterns within such networks.

In this regard, this work is driven by the urging need to address these problematic areas and explore a new approach that accounts for the dynamics of information flow within social networks, and put forth a way to assess the performance of BIM-based design.

3. An alternative approach for modeling design workflow

The alternative analytical approach developed in this study consists of using agent-based modeling to integrate two aspects in order to reflect the complexity of the design process: the social network topology and the design information dynamics. The design process of construction projects is a complex system consisting of a large number of individuals working within geographically dispersed teams with multiple backgrounds and trades who are all gathered to deliver a project with limited resources such as time, cost, and information. With current shifts in traditional design and project delivery and introduction of BIM-based design and life-cycle management, it becomes obsolete and ineffective to analyze design workflow independent from the interactions of these teams that bring about the design delivery process.

Agent-based modeling (ABM) is a new approach for simulating the behavior and interactions of autonomous agents with complex interdependencies. Agent-based modeling is the simulation of occurrences as dynamic systems of interacting agents to analyze the collective behavior of agents within a system in order to understand underlying phenomena and apply certain improvements for the whole system and individual agents as well. Agents can represent people, cars, information, resources, companies, atoms, etc. ABM regards the modeling of agent interactions and relationships with other agents and modeling its behavior which depends on the situation and its environment [11].

The environment considered in this research is a social network topology, depicted schematically in Figure 1, consisting of two types of agents: (1) the person (or individual) agent and (2) the design information deliverable agent. This topology represents the nodes as the people performing design or involved in the design decision-making process, the links (edges) representing interactions and communication between the people agents. The individual agent has attributes such as demographic information, number of connections he/she has, frequency of information exchange, time spent working, etc. The links, in earlier studies, have been regarded just as mere connections and what flows within them has been disregarded. These interactions as well as the exchange and interdependence of information create an emergence of new information and behaviors. Using social network analysis (SNA), these interactions and the topology of connections between designers help visually understand some characteristics of the social network structure. Not only does SNA examine the structure of the relationships between the individuals, it also studies the natural mechanics occurring within. SNA helps researchers understand the network data visually, convey the results of the analysis, and reveal any hidden properties that might not have been captured through qualitative measurement. Quantitative analysis can also be performed to relationships, connections, and characteristics pertaining to an individual node and to the network structure as a whole using some metrics presented in Table 1. Such metrics reflect the environment of communication, where individuals might work as collaborative teams or as isolated entities, exist as segregated clusters or one coherent network unit, work within a centralized or decentralized decision making hierarchy, facilitate the flow of information or make it interrupted based on their interactions. Other insights can be obtained through the observation and analysis of network topologies.

In the topology presented in Figure 1, and in order to account for information flow within these links, an information deliverable agent is created representing design information deliverables such as BIM models, design drawings, calculations, etc. The time spent under rework, design, review, or being queued, are also attributes that can be determined for a deliverable. The figure also shows the overall project social network attributes such as the type of the project, contractual setup, number of teams involved, and the network structure characteristics, which are important in understanding and justifying network behaviors and outcomes. The simulation resulting metrics and trends of information flow can be obtained such as the total number of deliverables shared over the project duration, value adding design time, total number of defective design generated, and bottlenecks inhibiting a smooth flow of data.

While ABM takes a reductionist approach that transforms the real world into a simplified model, it more importantly allows us to capture emergent behaviors of the overall network behavior that cannot be obtained by simple observations or assumptions of individual agent behavior, better understand how design information flows between participants, and underline the role of the social structure in influencing the diffusion of design information. By measuring and analyzing the behavior of individuals and information flow within the entire network through ABM, unpredictable outcomes that are hard to see through simple observations or assumptions are made clearer and more understandable. Traditional analytical methods fail to capture the resulting emergence of collective behavior and dynamic relationships between agents, and they usually represent a static description of the system at one frame in time. These limitations of regular approaches discussed earlier lend the need to use agent-based modeling to model the behaviors, interactions, exchanges, and formations of teams that influence individuals' and the system's emerging performance.

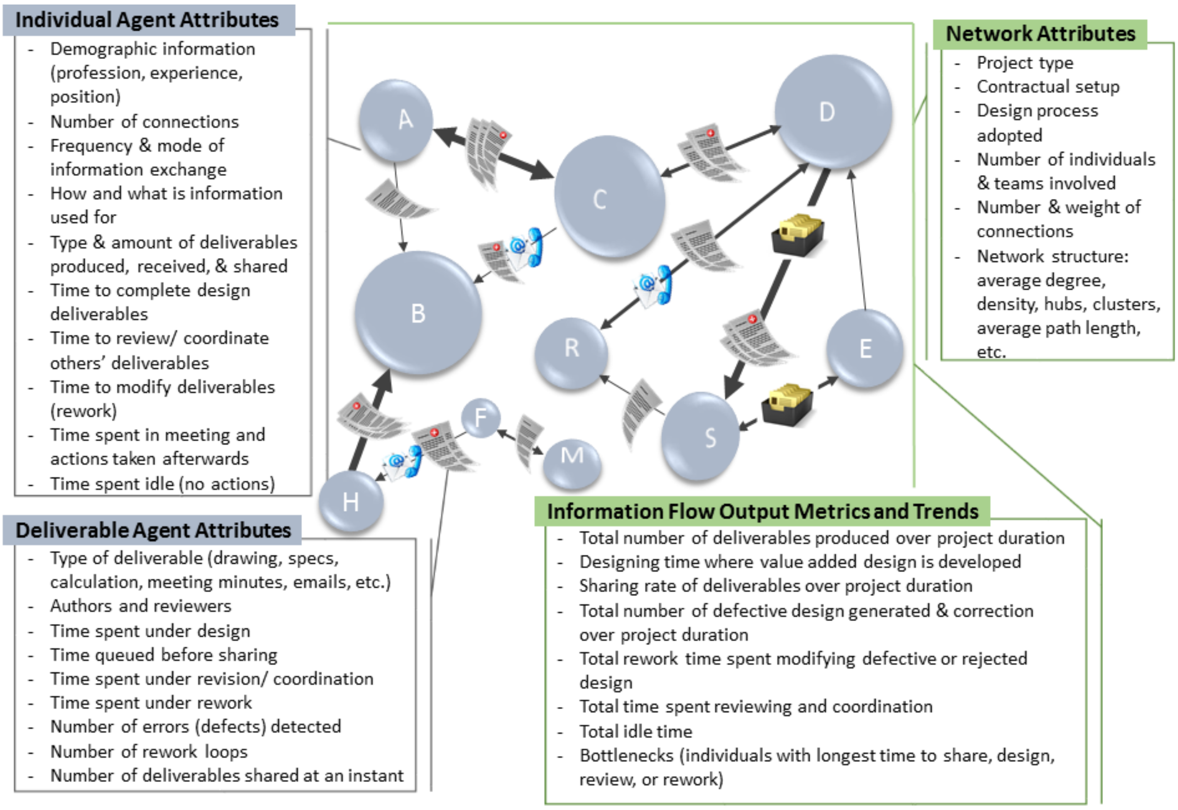


Figure 33. Social network topology of agents and metrics

Table 24. Social network metrics

Type	Metric	Definition (this metric describes)
Node	Degree centrality	Measures the number of links an individual has with others
	Betweenness	Measures the number of node pairs that an individual connects or bridges (serving as a broker or intermediary)
	Closeness	Measures the number of links from an individual to others; how reachable a person is
Network	Density	Measures how many actual links exist between nodes divided by the number of total possible links to reflect cohesiveness of the network
	Clustering	Measures how clustered groups of people are compared to the rest of the network indicating existence of closed triads and small communities
	Average path length	How many steps, on average, nodes require to reach each other
	Modularity	How dense connections are between nodes within groups compared with other groups

3.1. *Agent-based model setup for BIM-based design workflow*

AnyLogic is a simulation tool that performs discrete-event simulation, system dynamics, and agent-based modeling. AnyLogic is used in this study to develop a model for understanding and measuring design workflow under BIM-based design network topologies. The model interface consists of two agents that were defined earlier (people and information deliverable agent). The behavior of each agent is represented through a "State Chart" that defines the behaviors or states of each agent, and provides the rules for changes in behavior and interactions with other agents.

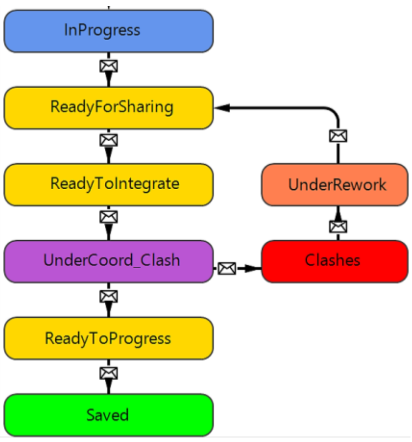
A person agent can have these interchanging states: "designing, integrating/coordinating, reworking/modifying design deliverables, sharing deliverables, in a meeting, being idle". The interchange or transitions from a state to another is dictated by interactions and requests from other people in the design process. For example, if a person is designing and someone requests input from him/her, he/she moves to the "Share" state after completing a certain design. The time invested in each state, and the transitions between states, are based on data that can be collected through surveys and observations of individuals and teams. The behavior of each agent throughout the project can then be simulated to show the changing dynamics throughout the design project and how the design process and exchange of information is flowing within the design network.

Similarly, the information deliverable agent possesses a different set of states. This agent exchanged between designers. This kind of agent is a mobile agent (it is transferred and exchanged) and its behavior is controlled by the behavior of its superior agent (designers). An information agent can have these interchanging states: “In progress, ready for sharing, ready for coordination, under integration/ coordination, approved, clashes detected, or under rework”. The interchange or transitions from a state to another is dictated by the decisions and behaviors of the designer agents. For example, a BIM model, moves from “Ready for coordination” state to “Under integration/ coordination” state when the people responsible for coordinating it start the “Integrating/coordination” state process. Data pertaining to the number of BIM models and deliverables exchanges over a time period, whom each person exchanges information with, how frequently deliverables are exchanges, the means of communication, the number of revision cycles of a deliverables, and other input can be collected through questionnaires addressed to the designers and by tracking data logs of such exchanges. Figure 2 is a sample state chart of a BIM model agent.

3.2. *Design workflow analysis through simulation output*

The characteristics of design workflow exchange of each individual, the state of each information deliverable, and the overall dynamics of information flow of the entire network can then be obtained. On the designer agent level, the simulation of the model can highlight interesting trends such as: the number and durations of design cycles which can help detect phases of idle time or non-value adding design and how time is divided between different design activities, number of rework and revision cycles conducted by the designer that can imply potential problems with design information and error diffusion mechanisms as well as conformance or non-conformance with design requirements and the introduction of client changes during design, and other attributes that can be explored in-depth in further research. Value-adding design workflow can be assessed from several perspectives, for example: sharing trends and frequencies which can reflect a smooth flow of information or batch interrupted flows that can result in efficiencies, queueing time experienced by information deliverables, the number of rework cycles which can reflect if information exchange patterns are efficient in delivering important data to the right people at the right time or turning data into obsolete information resulting in errors that require rework, and other trends that can reflect underlying issues in the communication and collaboration processes involved in the design process. On the information deliverable level, the simulation can show the length of time a model can be held in queue with a designer before it is shared, reviewed, reworked, or before a decision is taken on it. Moreover, the number of times it is revised, reworked, modified, shared, and the number of errors and design non-conformances can also be tracked for each deliverable.

A sample of information exchange patterns resulting from interactions is depicted in Figure 3, showing the total number of deliverables shared each day (black line) and those shared by a specific department such as architecture and civil engineering (blue and purple respectively). It shows peaks in sharing and interruptions at other intervals, which can reflect tendencies to withhold information, wait for completion of design, or directly share before completion.



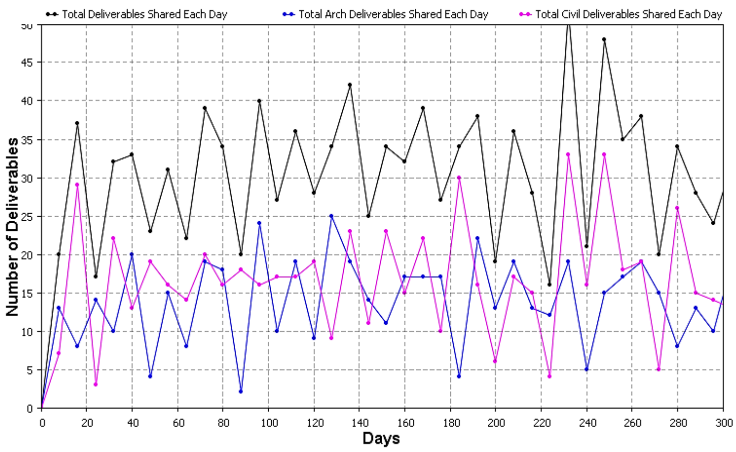


Figure 34. State chart of a BIM model agent

Figure 35. Information sharing trends on the overall project

On the collective network behavior level, several insights that describe design workflow on social networks can be obtained. For example, patterns such as the exchange of design information throughout the project can reflect whether workflow is smooth or interrupted, whether information is being shared continuously between designers or stored in silos then shared in batched resulting in outdate data that can be later manifested as errors in other deliverables. Bottlenecks in processing times (reviewing, coordinating, designing, or sharing) of individuals or teams can also be detected and help indicate where actions need to be taken. The overall quality of design information reflected in the dynamic generation and diffusion of errors between teams over a time span can also be observed to highlight root causes of resulting trends. In addition, design information production patterns can show when and how information is being produced, stored, queued, and can provide insight on drivers or preventers of design generation. Further insights on design workflow attributes and the influence of interactions and topologies of networks can be explored.

4. Conclusions and potential implications for BIM-based and collaborative design

The proposed method of integrating social topologies and design process dynamics through agent-based modeling can provide a different perspective for understanding the diffusion of information between parties involved in the design process on BIM-based design projects. The developed approach is an attempt to improve on and bridge the gaps of the existing analytical tools to accommodate complex systems in terms of involved teams, sophisticated requirements, integrated technological interfaces, and large amounts of information that needs to be coordinated and effectively exchanged between the responsible parties. The analysis of the communication network topology and design workflow patterns can help determine the existence of a potential link between how teams are structured and the impact of such a network structure on the status of design workflow. The social network topology and the resulting patters of workflow dynamics can be cross-checked to highlight potential relationships of collaboration and team coalitions on shaping the quality and flow of information. Moreover, the proposed approach can allow for a quantitative and qualitative analytical comparison of BIM-based design processes and different project delivery approaches to traditional design trends. These comparisons can set a working standard and highlight potential benefits resulting from BIM use and collaboration between teams, and benchmark performance to desired norms to guide decision makers to take necessary actions. This analytical method can be further explored in other dimensions, phases, and the project-life cycle as a whole. The underlying theory can be tailored to suit any phase and model complex systems that are continuously changing over time and involve high levels of interdependence and interactions of their components.

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Current Issues of BIM-based Design Change Management, Analysis and Visualization

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Abstract

The BIM-based design process is dynamic in its nature as the models typically need to evolve. This paper addresses the problems of a BIM-based design change analysis, design change management and visualization of the changes made to BIM models. A concise discussion of the general problems of design change management in terms of BIM is presented. The authors also briefly discuss the current advancement of native BIM tools and their functionalities dedicated specifically to design change management; namely, tracking and analysis of design changes on the basis of BIM models. Subsequently, a number of examples are presented to illustrate the results of recent developments in the visualization of design changes.

Keywords: design change management, design change analysis, design change visualization, BIM.

1. Introduction

BIM (Building Information Modeling) is currently an intensely discussed topic among professionals and scientists all over the world. A broad definition of BIM explains it as a collaborative platform for efficient information exchange and sharing among different disciplines [1]. “I”, which stands for “information”, is actually the key in understanding, implementing and using BIM. A thorough discussion and review of the ideas and approaches to BIM in the context of the information stored in the model and its processing in the course of a construction project is presented in one of the authors previous publications [9]. The goals of this paper include the following: to discuss briefly the problems of BIM based design change analysis and to present the authors’ point of view to this problem, to present the current advancement of native BIM tools in the field of tracking and to analyze the design changes on the basis of models given in the IFC standard.

1.1. *Brief literature review*

The development and evolution of BIM affects the construction projects in all their areas and phases. Change management in the BIM context gains attention in many publications, as in the ones chosen to present here. One of such publications addresses the problem of change management in early design [6]. Its authors discuss the topic and problems of object versioning within BIM models given in the IFC standard. In another paper the flexibility of BIM tools towards design changes was studied, in which the authors evaluated and disclosed the drawbacks. It was concluded that BIM is efficient in adopting and promoting changes in the model; however, it suffers from certain shortcomings, such as the inability to produce a comparable design change deviation report, the unreliability of bidirectional links between the external analysis software and BIM tools, not having a powerful user interface and lacking enough artificial intelligence to analyze and offer alternatives to design [8]. The authors of another study propose an ontology of design changes [7]. According to them, the ontology explicitly defines a BIM-based structure to organize the changes. They complement the idea with the concept of an integrated framework the aim

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of which is to enable an information update process on a BIM model, and to facilitate information flow and exchange for energy efficient design [integr framework]. In a later study [5], the authors presented an automated model based on BIM, developed to aid the visualization of the design changes requested by owners after the completion of the design phase and before the commencement of the construction phase.

This paper is a continuation of its authors' diverse work, research and involvement in discussions concerning BIM in its various aspects, presented in earlier publications, for example [2], [3] and [9].

1.2. *BIM based design change management: basic information*

Design change can be defined as the alteration made to the hitherto proposed design solutions. Regardless of the reasons for design changes, they require re-design, or at least an introduction in successive revisions. In the traditional approach to design change management, the occurrence of which is considered inevitable in construction projects, attention is focused on the efficiency of the information and document flow, such as change requests and design revisions. Emphasis is put on reacting to the need for a design change, developing design change solutions and distributing design revisions among the participants of the construction project.

One of the general assumptions about BIM implementation in construction projects is that they will involve the reduction of design errors and, in consequence, reduction of the design changes forced by these errors (compare, for instance, [1]). However, even if BIM is applied to a construction project, it seems impossible to completely eliminate design changes. According to the results obtained by Malaysian researchers [8], the professionals that were investigated claimed that hardly any of the projects implementing BIM they had known was free of design changes. Another investigation [7] led to the development of a BIM-based ontology of design changes. The taxonomy developed included six classes explaining the nature of design change by its type, changed attributes of the altered component, dependencies between the components, the level of change effect on other components, timing (stage of the project when the change occurs), the impact on cost and schedule. The authors' proposal is to add one more class which would help to explain the cause of the change. In authors' opinion, the causes of the changes introduced in BIM models may be divided into two main subclasses. The first subclass should encompass the changes which occur as a natural consequence of model development that is, refining the model by the design-team, refining the model due to the analyses performed by engineers and consultants and redefining the model due to the client's requests. The second subclass should encompass the changes the occurrence of which is not a natural consequence of model development: removal of indefinable design errors, corrections due to unforeseen internal constraints of a construction project and corrections due to alterations of external conditions. The application of the taxonomy may provide the necessary structured information about the changes made to the model for further analyses and use.

BIM-based design change management can be defined as a dynamic process providing identification of needs and reasons for changes, implementation of the changes to the model (while keeping its integrity and coherency), the flow of information about changes, analysis and assessment of the consequences of changes and minimizing the negative effects of changes while ensuring multioperability. The BIM-based design change management defined in this way needs appropriate tools and techniques that will ensure effectiveness of the process.

2. Development of native BIM tools in terms of design change

BIM is a technology which, if implemented in a construction project, can be immensely helpful in managing information and data. One of the greatest advantages of BIM in the context of design change management is that it allows to alter or modify the components of the model in real time. The information stored in the model is rearranged and the changes are available in every view. However, the problem is that for now the user "(…) is only able to see a change, and the newly-affected model, but not the ripple effect of that change" [5].

Literature analysis and discussion with BIM professionals helped to identify the need for a specific BIM-tool development. It was assumed that such a BIM-tool must be capable to visualize the changes made to the model in the course of the design process and to support the analyses of the consequences due to these changes. The basic assumptions for the tool are briefly presented below.

In the successive steps of the design process, that is, in model development, the subsequent versions of the model are introduced. These versions can be regarded as emanations of a dynamic design process. It must be stressed that they constitute a basis for a variety of multi-disciplinary analyses. In the successive versions of the model (later referred to as model revisions) a number of alterations can be made. These changes may be compared with each other and considered in many aspects. As a matter of fact, it may be necessary to compare several revisions of the model. Summarizing, the expectations were defined for the tool and it was agreed that it should allow to:

- compare two or more revisions of the model given in the IFC format,
- visualize (highlight) the changes made to the components of the model,
- differentiate the visualization of changes in terms of modification, addition and deletion of the component,
- highlight the changes made to the attributes of the model components,
- utilize the information about the changes in the cost and time analyses of the project,
- inform the user about the changes in a clear and understandable way.

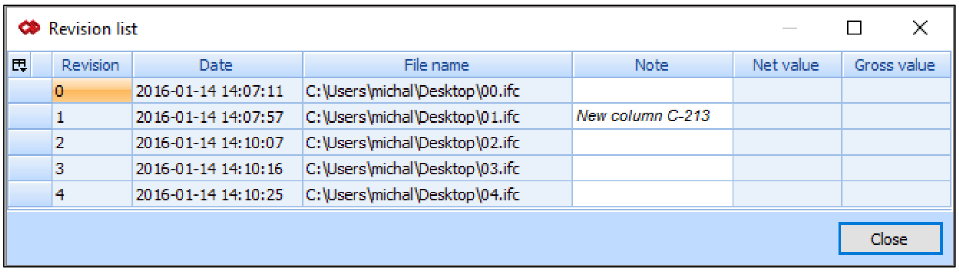
It has been decided to implement such functionalities in BIMestiMate, a Polish BIM-based 4D and 5D analysis application. BIMestiMate is a computer application being constantly developed by Datacomp sp. z o.o. company from Poland. The program enables an almost full automatization of the quantity take-off process using its own calculation engine which is embedded in the IFC viewer attached to a calculation sheet. When a model is loaded into the program, both the model and a calculation sheet appear. The sheet's layout is based on a model's IFC structure. BIMestiMate also supports schedule preparation. The essential assumption was that implementing functionalities that support design change management in the BIM-based 4D and 5D system will enable not only visualizing the changes between revisions r_i and r_j but also the impact of these changes on cost and time. The comparison of the cost calculated on the basis of r_j revision and r_i revision would take into account only the changes, as there would be no need to prefer the whole estimation from the very beginning onwards.

Current advancements in the development of the functionalities listed are presented in the next section of the paper.

3. BIM based design change analysis: examples

As far as BIM is concerned, design change management seems to be one of the biggest advantages. BIM assures that any change made during each phase of the project will be revealed immediately on each view and those changes (improvements by default) will be proficiently managed by the participants of the construction project. Such idea looks exquisite by definition but making this a reality needs efficient tools on which BIM-users can rely.

These assumptions formed the basis for recent development of the functionalities and tools that aid change management within BIMestiMate application. The application enables to load and compare an unlimited number of versions of the same model, that is, revisions. In Figure 1 one can see a screenshot of the application window summarizing a revision list. Notes can be added for each revision and, if available, brief information about costs is displayed in the "Net value" and "Gross value" columns.


Revision list

Revision	Date	File name	Note	Net value	Gross value
0	2016-01-14 14:07:11	C:\Users\michal\Desktop\00.ifc			
1	2016-01-14 14:07:57	C:\Users\michal\Desktop\01.ifc	*New column C-213*		
2	2016-01-14 14:10:07	C:\Users\michal\Desktop\02.ifc			
3	2016-01-14 14:10:16	C:\Users\michal\Desktop\03.ifc			
4	2016-01-14 14:10:25	C:\Users\michal\Desktop\04.ifc			

Close

Fig.1 – Revision list - (source: own study)

Basically, the BIMestiMate functionality of design change management is composed of a few groups of functions. Figure 2 presents a screenshot of the application with available functionalities for selection, displaying and distinguishing between changes options. The user is able to display either modified, removed or added components. A graphical representation and filtering changes options are available – using color distinction the user can show the elements that have been modified regarding occurrence, geometry, classification or properties.

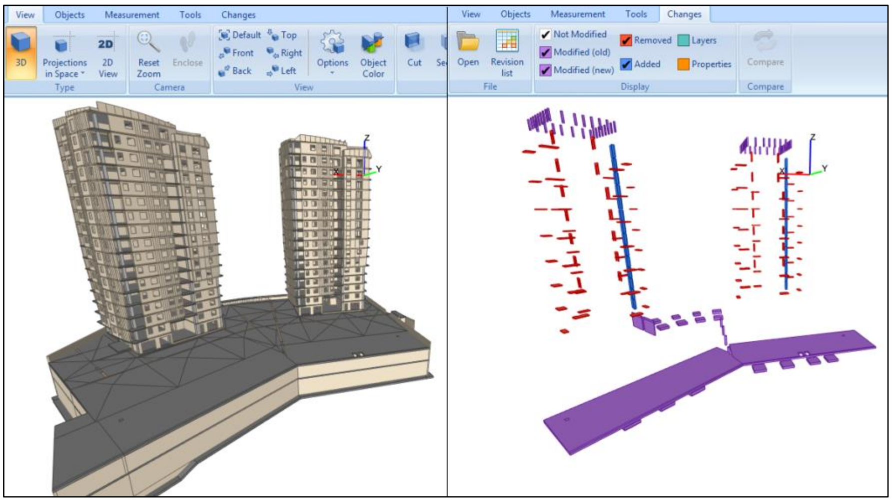


Fig.2 – A view of BIMestiMate embedded IFC viewer window – normal view (left side), tab with change management functionalities (right side) (source: own study)

The application functionalities make it possible to compare visualization and parameters of the chosen component of a model on the basis of two selected revisions, since the viewer can simply be switched between changed elements. The user can easily track the changes made to a certain component in the successive revisions by comparing the selected revisions. In the upper part of Figure 3 in the left window one can see the options for the choice of revisions to compare when in the right window ”Two latest revisions” have been selected. “Slide” enables moving the objects inspected closer and further from each other. Different views are also presented in the upper part of Figure 3.

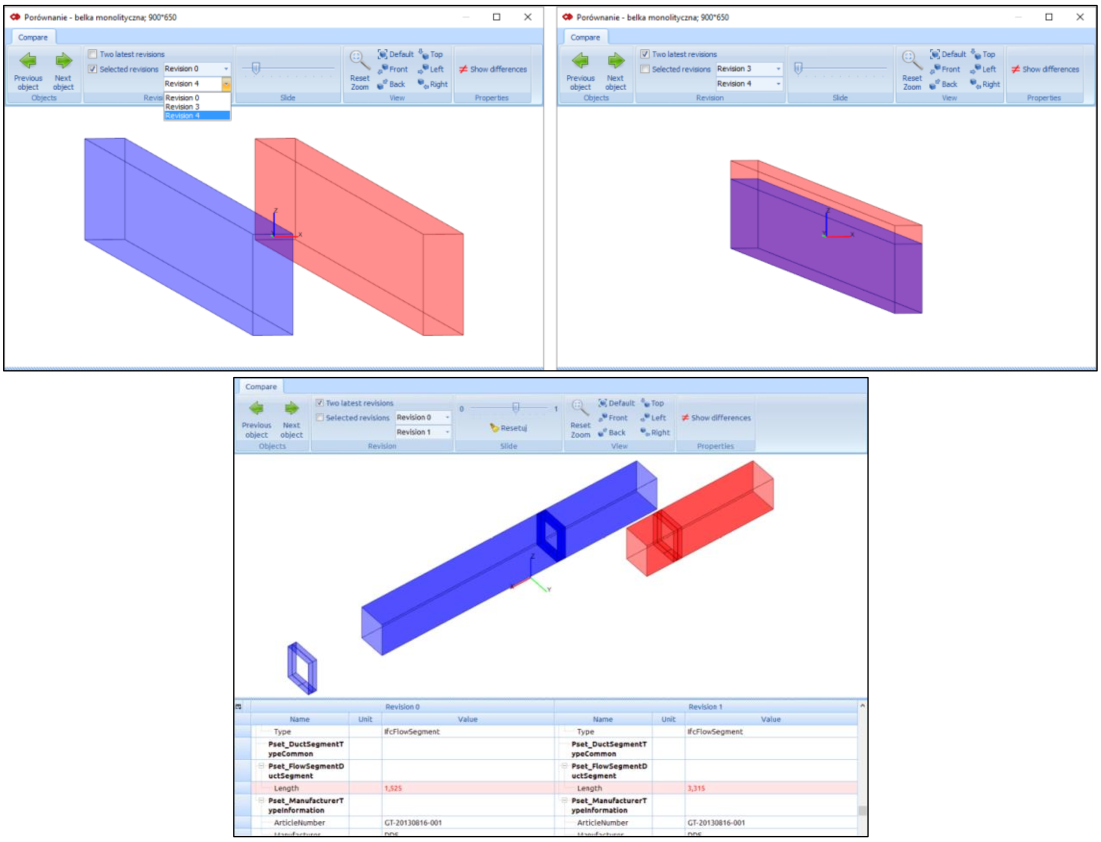


Fig.3 Options of visualizing and displaying information of alterations in two chosen revisions - (source: own study)

In the lower part of Figure 3, apart from the view of the changed component, one can see displayed information related to the changed parameters of the component according to the two chosen revisions of the model. A readable list of changes attached to the viewing window allows to display and highlight the alterations of the properties or values for an easy detection. Figure 4 presents the view of the model with the displayed and highlighted components that have been changed (on the right) and a list of properties and their values for a chosen component. The application provides convenient viewing and setting the zoom and camera configurations.

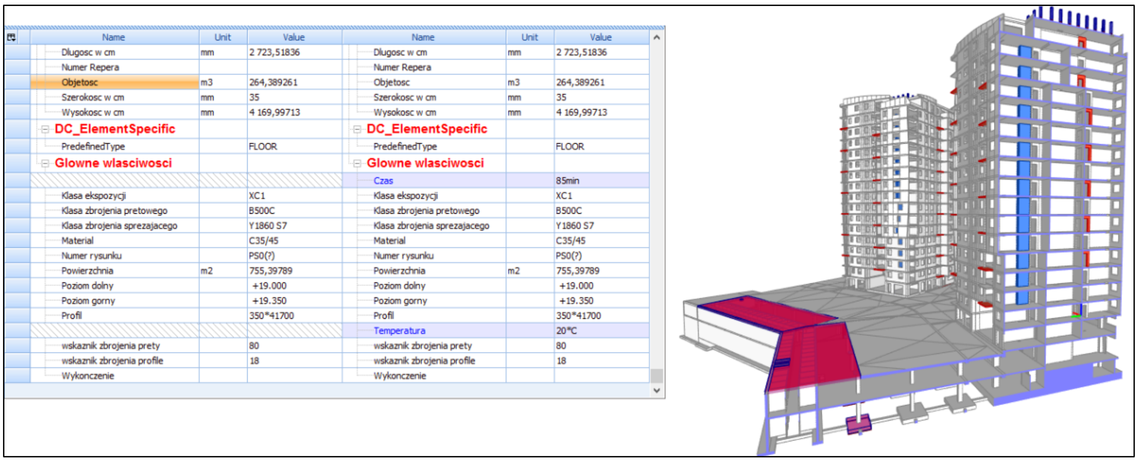


Fig.4 – View of the model changes - model view and a readable list of parameters - (source: own study)

On the basis of the detected and processed changes BIMestiMate supports cost analyses. The application provides the possibility of creating cost estimation variants resulting from successive revisions (alternative or improved versions of the model). In consequence, it allows either to prepare an analysis of changes impact on cost or to build a cost simulation for alternative design proposals or solutions. It makes the decision process for the final design better informed. Figure 6 depicts a cost calculation sheet beside the view of the model where the changes made to the model are highlighted both in the list and in the model view.

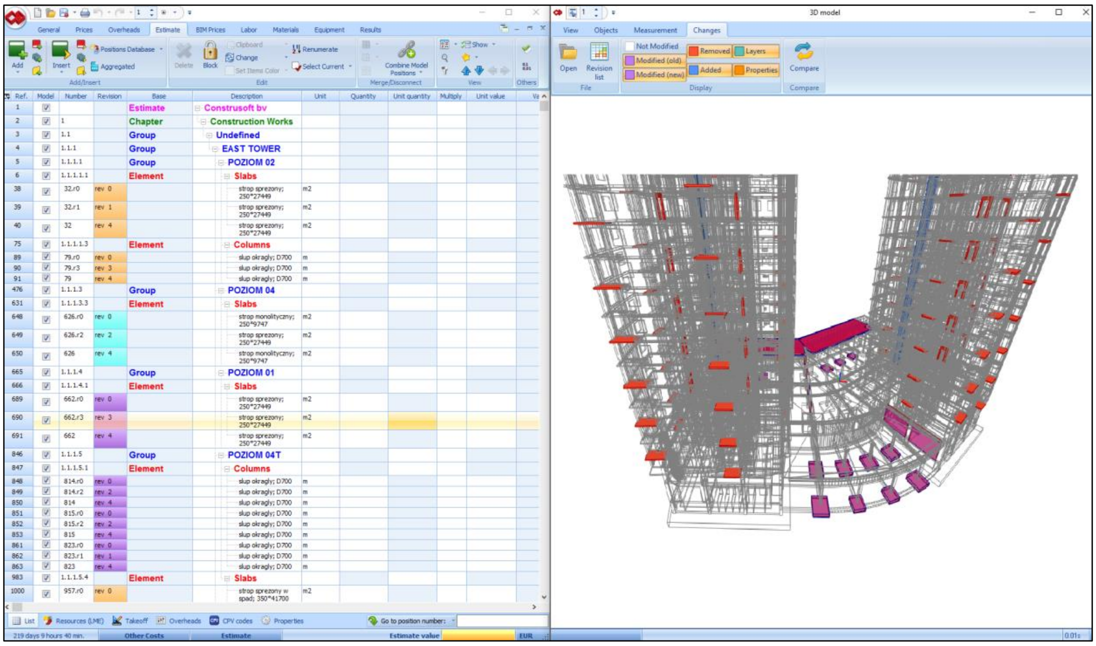


Fig.6 - Revisions-based cost analysis process - (source: own study)

BIM, in terms of a model, constitutes a shared database of information about the construction object. The database evolves during the design process as changes are made to the model. Due to the automation of quantity take-off, support of the cost estimation process and functionalities which allow to find and process the changes made to the model, which are implemented in BIMestiMate, all the participants of the project are able to investigate and compare the impact of model alterations or variants on project costs.

For now the application presented in this paper supports BIM-based scheduling. In the near future the development of the functionalities that allow to assess the impact of the changes on project tasks and the whole project duration is planned.

4. Summary and conclusions

Despite the fact that one of the goals of the BIM implementation in construction projects was to reduce the number of design errors, design changes seem to be inevitable in the process of model development and improvement. BIM, as a technology, should provide both the possibility to present and analyze the consequences of the changes. The potential of BIM should be used to automate or semi-automate the execution of analyses.

The development of BIM tools that allow to implement BIM-based design change management in an efficient way seems to be both actual and challenging task. Such functionalities as quantifying, visualizing and analyzing changes made to models would provide benefits for all participants of the construction project. Currently, successive revisions of models usually do not highlight the alterations of information, component attributes or relations between the components caused by the changes made to the model. These limitations are being consistently overcome along with the development of the BIM tool introduced in this paper. One of the goals of BIMestiMate development is to provide an efficient and automated BIM tool that supports BIM-based design change management process: a method for collection, distribution and processing information concerning changes among the participants of a construction project. Depending on the current advancement of work, for now BIMestiMate allows the user to:

- load and process several revisions of the model given in the IFC format,
- compare two revisions of the model given in the IFC format,
- visualize and display changes made to the model in successive revisions, both in terms of alterations made to the components and the parameters or values of the component attributes,
- utilize the information about the changes in the cost analyses.

Further research and development of the tool will include testing the tools by the BIM specialists, improvements of the existing functionalities and the implementation of new ones. Planned development directions are as follows: increasing the information detail level that may be compared and developing the analyses capabilities, especially in terms of automation of the processes.

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The authors wish to thank M.A.D. Engineers sp. z o.o. (team of BIM specialists) for providing a number of models used in analyses and tests of the tools and functionalities presented in this paper.

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A BIM-based Dynamic Model of Site Material Supply

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Abstract

Construction site material supply is one of the major issues in construction planning. Due to the space inadequacy of construction site in downtown area, material supply problems exist in almost every construction site regarding how to manage material amount, approach time and stack positions in construction activities, thus lead to low construction efficiency, high project cost and other problems. Moreover, the current material supply scheme is designed only once before construction without consideration of the dynamic nature of the supply problems. With the development of BIM technology, it provides a potentially valuable tool for these problems. This paper presents the development of a BIM-based dynamic model of site material supply that is capable of identifying optimal dynamic scheme for site material supply —what (material), how many, when, and where. The method of 4D modeling is investigated, as well as the acquisition method of site information, and the optimal scheme generation method. Contributions include the development of the BIM-based site material supply management system, and a case study for the process of the site supply scheme implementation.

Keywords: BIM; dynamic model; material supply; construction site

1. Introduction

In official records, there were 46,456 million yuan value-added of construction industry in China in 2015, which is an increase of 6.8% over the previous year [1]. With the increasing of construction scale, a large number construction sites have sprung up in city, such as Wuhan city has more than 10,000 construction sites [2]. For the sake of inadequate spaces for construction site in congested urban areas, every construction site has the material supply problems [3] (material amount, approach time and stack position [4] [10]). For example, inappropriate stack position will take more time to re-position the material, low construction efficiency, high project cost and the like. Therefore, a good material supply scheme is required. Presently, the material supply planning for construction site is based upon the personal experience [5], and it is designed only once before construction without considering the dynamic nature of the supply problems, including dynamic changes of the material demand and the site information in different construction phase.

A number of scholars have carried out relevant research on the above problems. Aiming at the dynamic problem of material demand, Ju Hyun Lee [6] used the RFID technology to track the site material to confirm the demand of material; Jongchul Song [7] developed a RFID and DPS based construction material management system, and realizes the material management in real time. About the dynamic problem of site information, IK Brilakis [8] identified a method of image retrieval in construction, and it can obtain site information through recognizing materials. To generate the optimal layout scheme, Khaled El-Rayes [9] presented the development of an Approximate Dynamic Programming (ADP) model that is capable of globally optimizing dynamic site supply plans of construction projects in order to minimize overall site supply costs; Xing Su [10] proposed a material layout evaluation model (MLEM) based on the material accessibility grade concept to integrate space and time in order to improve material accessibility and reduce time waste; Hisham Said [11] presented the development of a new congested construction logistics planning (C2LP) model that is capable of modeling and utilizing interior spaces of buildings under construction to generate optimal logistics plans.

However, on one hand, existing studies are all focusing on one or two problem such as stack position only. Though they proposed the solutions, a proper scheme requires a comprehensive consideration of these issues. On the other hand, the solutions are one-time optimization of the scheme without considering the dynamic change with construction schedule. Construction site conditions are dynamic in nature, involving numerous activities and resources scattered on a usually congested site [12]. The reason for these difficulties lies in the fact that there is no information integration tool as the basis of information sharing in site material supply management.

With the development of BIM technology, it provides a potentially valuable tool for the site material supply problems. BIM is a highly integrated project information tool, it is mainly to build a data model with a variety of project information, and then use the information model to support the project design, construction and operation [13]. A suitable site supply model can realize the reasonable arrangement of materials, and help to improve the production efficiency. This paper uses the BIM technology to establish a dynamic model of site material supply about the material amount, approach time, and stack position on the basis of construction schedule.

2. Research methodology

The objective of this research is to develop a comprehensive, informative and practical BIM-based application for the purpose of BIM-based dynamic model of site material supply. Fig. 1 illustrates its framework, in which the model integrates Material Demand Dynamic Model, and Site Layout Dynamic Model, and generates Site Drawing with respect to site-level and floor-level and Material Supply Plan Table in terms of Name, Amount, Time, and Position.

Information about material demand dynamic model (4D model) is extracted from the construction schedule and the building design. The construction schedule, the core of the whole model, is required to determine the material approach time. At the same time, it can support the building design in order to confirm the name and the quantity of the required materials in each construction phase.

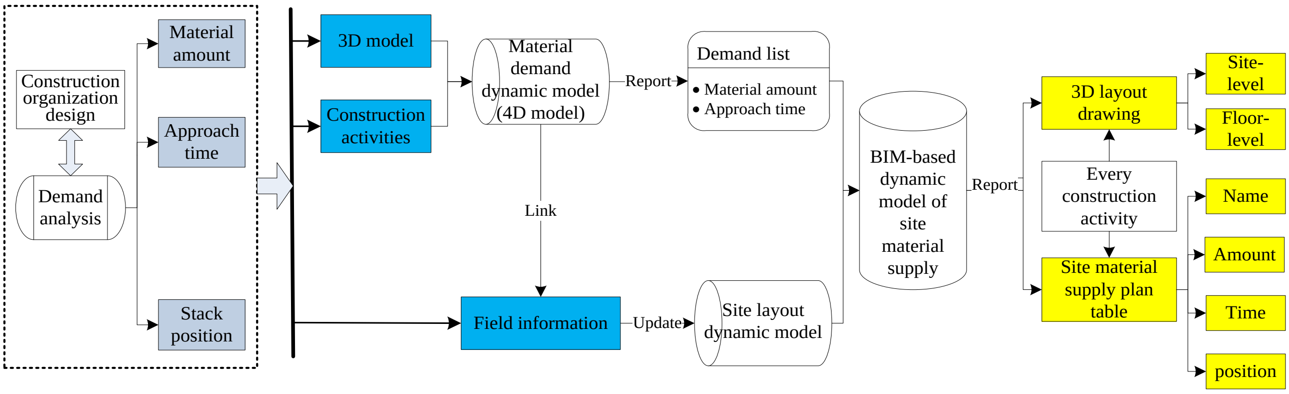

Figure 1. The framework of BIM-based dynamic model of site material supply

Site layout model comes from the link of 4D model and field information. The site information included static information and dynamic information is the basis of confirming the material storage location. Static information mainly refer to site drawings (includes building location, access ways, major equipment location, and work spots, etc.) of each phase generated by building design, and It converts the site drawings into polygons to represent the total site area. Dynamic information needs to collect the dynamic site information through the image acquisition technology corresponding to construction schedule.

3. The demand analysis of site material supply management

3.1. *Function analysis*

Site Material Supply Management is mainly for the management of supply situation contains the time when to approach, the position where to stack, and how many amounts of the material. The main function of the site material supply management includes the following parts:

- Material approach time management: according to the construction schedule, determining the material approach time of each construction stage, and allocating materials in an orderly approach;
- Material amount management: according to the building design and construction schedule, determining the amount of material used in each construction phase, and supplying a certain amount of material into the site;
- And material stacking location management: after a certain amount of material approaching at a certain time, the position of the material can be arranged according to the site condition.

3.2. *Information analysis*

The basic information of site material supply management in the completion of various functions as shown in table 1:

Table 1. Required information in site material supply management

Function	Information	Remarks
Material approach time management	Scheduling information	Construction activities；duration
Material stack position management	Static information in site	Site division; region number; region size
	Dynamic information in site	Region status（whether or not to be occupied），other location
Material amount management	Design information	Material name、name、amount of each phase

4. BIM-based dynamic model of site material supply

On the basis of demand information analysis about the site material supply management, this paper presents BIM-based dynamic model of site material supply comprised all the required information. The dynamic model is shown in Fig 2. The dynamic model mainly includes material demand dynamic model and site information dynamic model.

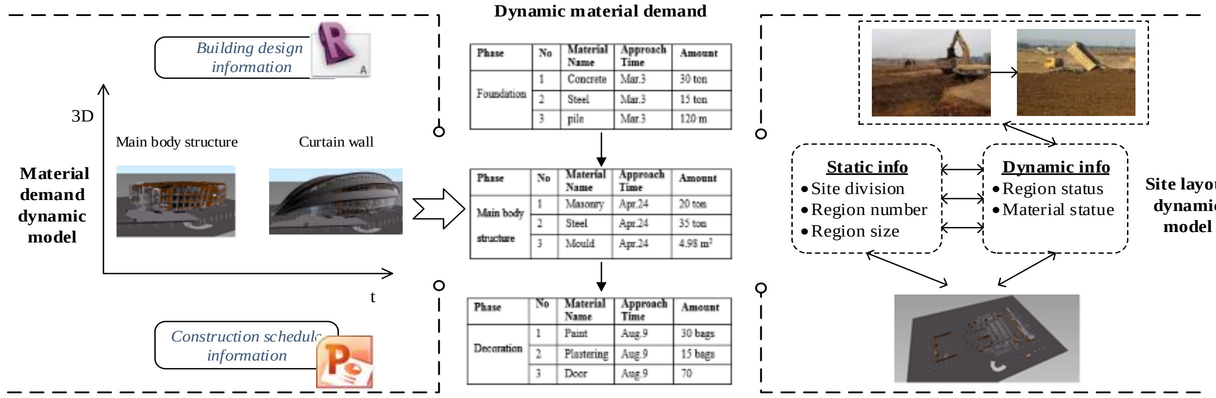

Figure 2. The dynamic model of site material supply

Material demand dynamic model is the foundation of the material layout scheme. The model consists of building design information and construction schedule information. Site layout dynamic model is divided into static information and dynamic information included region status and material status.

4.1. *Creation of the material demand dynamic model*

Material demand dynamic model consists of two parts. The building design information is expressed by Autodesk Revit, and generates the 3D model [14]. Revit is development by Autodesk Revit Company and applicable to architectural, structural, mechanical and electrical modeling and software design. Using the Autodesk Revit can create custom site materials regional group, and add position number, length, width and other properties to a divided region, which is convenient for later identification and localization of the material regions. Finally, the 3D model is derived for a model file, and shared to the next phase.

Facilitating site material supply management processes with BIM, so that the supply scheme can be arranged and adjusted dynamically along with the actual construction process. Schedule information should be integrated with the 3D model, and form the 4D model. The construction schedule created in the MS Project is added to the 3D model by linking each component of the 3D model to the correlative work breakdown structure node [15]. The process is showed in fig 3. In addition, the construction process can be virtually presented in time sequence by attaching start and finish times to each construction activity [14]. According to construction contents, construction process can be divided into construction foundation, the main structure, building decoration, the roof of building, the drainage and heating etc. This is convenient for site material reasonable supply scheme according to different construction process.

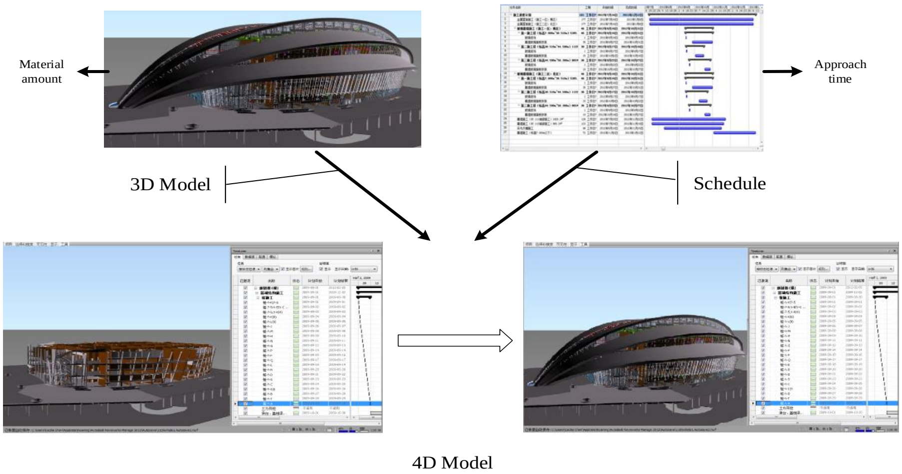

Figure 3. The process of material demand model

4.2. *Site layout dynamic model*

After confirming material amount and approach time, stack position of material is demanded to be determined. With the change of construction schedule, construction site information is constantly changing. So there are different optimal stack positions for the material in different construction phase. It needs support of site information in every construction phase. And site information includes static information and dynamic information.

Site division, region number and region size belong to static information. There has create site region attributes in the above 4D model, and every divided region has the specific size, position, application, and the like. Meanwhile, the region for stacking will have the number information. The information above is aggregated to generate the site basic model of each construction stage. To determine stack position also need site dynamic information such as region status (whether it is occupied), material status (type and position). Collect site information to obtain the region status and material status. Then, relating the status information to the site basic model as attributes [16].

4.3. *The generation of optimal material layout*

Genetic algorithm (GA) is used to assist the stack position on the basis of site basic model [17]. The essence of the problem is to build a relationship between the two parts. In the above model, site is divided into many appropriate regions except the build, facilities, road and other usage. And materials and regions have been assigned specific numbers. Using the permutation type as genetic coding and randomly generates initial population. Then, reproduce new populations through choose, crossover and mutation. Fig 4 reprents the Genetic Algorithms operation flow. The objective function and constraint condition are as follows.

Minimum transport distance of workers [18]: MinisizeTD= $\sum_{i=1}^{n}\sum_{j=1}^{n}\delta_{ij}w_{ij}d_{ij}$, (1)

Constraint conditions: $\sum_{i=1}^{n}\delta_{ij} = 1$, {i=1, 2, 3,…n} and {if δ_{ij}=1 then (i ∉ R or j ∉ M)} (2)

Where *n* is the number of materials; δ_{ij} is the permutation matrix variable. *w* is the priority weight of a material *j* relative to a region *i*. *d* is the distances between a region *i* and a material *j*.

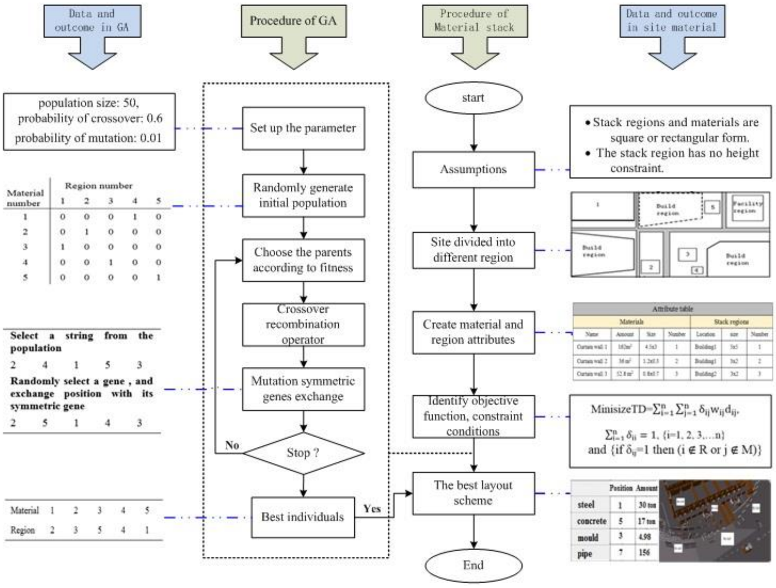

Figure 4. Optimal material layout operation flow

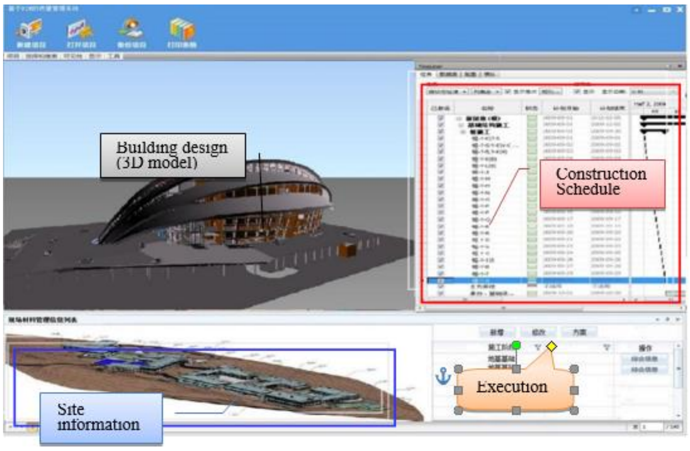

Figure 5. The system of site material supply management

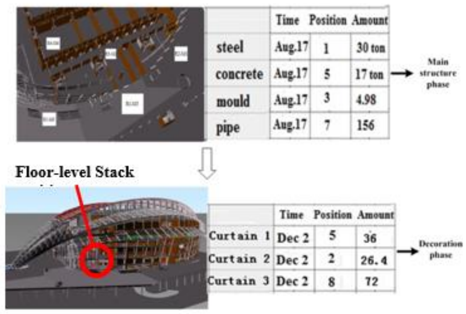

Figure 6. Layout drawing and plan table in two phase

5. Implementation

In order to verify the effectiveness of the BIM-based dynamic model of site material supply, a BIM based site material supply management system is developed. The system is shown as fig 5. And the outcome in two phase is shown as fig 6.

6. Conclusions and future work

On the basis of demand analysis about the site material supply management, this study presents BIM-based dynamic model of site material, and introduces the implementation process of the optimal supply scheme through a case study. The main conclusions are as follows.

- BIM technology is introduced into the construction site material supply management, the establishment of dynamic model is discussed, and it realize the value of BIM in the field of material supply management;
- The material demand dynamic determined the material amount and the approach time and the site information dynamic model determined the stack position are combined to achieve the integration of multiple information;
- 4D application ensures the timely scheme generation of the whole process, which helps the project participants to better solve the site material supply problem.

However, the research does have some limitations, such as the research is still in the stage of theoretical research. Future research will focus on the implementation of the model.

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A BIM Based Approach for Quality Supervision of Construction Projects

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Abstract

Quality supervision is an important means to ensure the quality of construction projects. Despite the variation in relevant standards of different countries, the core of supervision is to inspect and control each major construction procedure. Up to now, some application software for quality supervision have been used in engineering. However, too many inspection items specified by the relevant standards, lack of experience of inspection personnel, and the process of entering the data in the original record into computers have led to the inefficiency of the inspection work and data falsification, which buries the seeds of risk for construction quality.
In order to solve the problems, a BIM based approach to improving the quality supervision of construction projects is proposed. Firstly, the requirements analysis of the system is carried out. Then, the IFC (Industry Foundation Classes) standard for BIM (Building Information Modeling) data is analyzed and an IFC based information model for quality supervision is established. Next, an algorithm is established to automatically generate inspection points based on BIM and the related standards. Finally, a prototype system using BIMserver.org as the platform is developed, which facilitates inspectors to check inspection points according to standards, to get smart tips when inputting data on mobile terminal at the construction sites and to automatically generate standard documents without second input. Compared with the traditional ones, the approach provides a great improvement for quality supervision of construction projects.

Keywords: building information modeling, construction, quality supervision, standards.

1. Introduction

The construction quality relates to the public safety and interests. It is mainly determined by construction process. Therefore, according to the relevant standards, the construction process is normally strictly regulated, which is called quality supervision. Despite the variation in the relevant standards of different countries, the core of supervision is to inspect and control each construction procedure. However, too many inspection items specified by the relevant standards, lack of experience of inspectors, and the process of inputting the data in the original record into computers have led to the inefficiency of the inspection work and data falsification, which buries the seeds of risk for construction quality.

Building Information modeling (BIM) [1] provides a new information management means. BIM models with attributive information can support the information sharing and collaborative work among the involved users, which makes it possible to improve the quality supervision. Park et al. put forward a conceptual framework using BIM, augmented reality and ontology-based data collection template for proactive construction defect management [2]. Kwon et al. proposed a defect management system for reinforced concrete work to avoid recurring defects by utilizing BIM, image-matching and augmented reality [3]. Tsai et al. proposed an approach for construction inspection based on BIM to improve the efficiency of inspection and reduce the burden of the inspectors [4]. But overall, the current research rarely take into account the related standards.

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In order to solve the problems, a BIM based approach to improving quality supervision of construction projects, which uses a quality supervision system based on BIM to be developed, is proposed. Firstly, the requirements analysis of the system is carried out. Then an information model for quality supervision based on IFC [5] data is established for the development of the system. Next, a key algorithm to be used in the system is established to automatically generate inspection points of quality inspection based on BIM and the related standards. Finally, a prototype system is developed by using BIMserver.org as the platform of BIM data and presented to illustrate the effects of the approach.

2. Requirements Analysis

According to the national standards in China, in order to ensure the construction quality, every major working procedure needs to be inspected effectively. Contractors will conduct the self-inspection first when a major working procedure is completed. Then supervisors from a contracted supervision company will confirm the inspection result on behalf of the society before the next procedure can be continued. Managers from a developer such as a real estate company may inquire the inspection state and result whenever they want. All the relevant inspection items, inspection methods and required quantity of inspection points are described in the standards [6].

In order to solve the problems described in Section 1, the quality supervision system based on BIM is designed. The users of the system include the relevant inspectors such as contractors, supervisors and managers. The key functional requirements have been established based on the standards and the result of investigation on supervision process, as shown in Table 1.

Table 1. Key functional requirements of quality supervision system based on BIM.

No.	Function name	Function description
1	Import, browse and operate 3D model	Import IFC data, view model and components hierarchically, operate model with zoom, translation and rotation to help inspector quickly get the inspection target.
2	Automatically generate inspection lots, items and points	Establish an algorithm to generate inspection lots, items and points automatically which can help inspectors establish inspection plan before construction and carry it out orderly and normally at the construction site.
3	Fill out customized forms	Complete supervision successively by filling out the customized forms with smart tips.
4	Automatically generate standard documents	The form completed at the construction site can be automatically converted into standard document without second input.
5	View the state and results of supervision process	View and monitor the supervision data transmitted from the construction site and count up the status and result of the whole supervision process.

3. Establishing information model and algorithm

3.1. *Information model of quality supervision based on BIM and related standards*

Based on the key functional requirements as stated in Section 2, an information model was derived for the development of the system by analyzing the relevant information, as shown in Figure 1.

It is obvious that a project is divided into many sub-projects of different level such as the part projects, item projects and inspection lots. Inspection points are randomly sampled from inspection lots and contain a series of inspection items to be inspected according to the standards. On the other side, BIM models with many relevant elements that are defined by space relationship such as floor and axis, elements type such as column and beam, and elements property such as material and area are assumed to be in the format of IFC, which is an international standard of BIM data. Inspection points and the elements are connected as inspection object to be applied to the quality supervision of construction process.

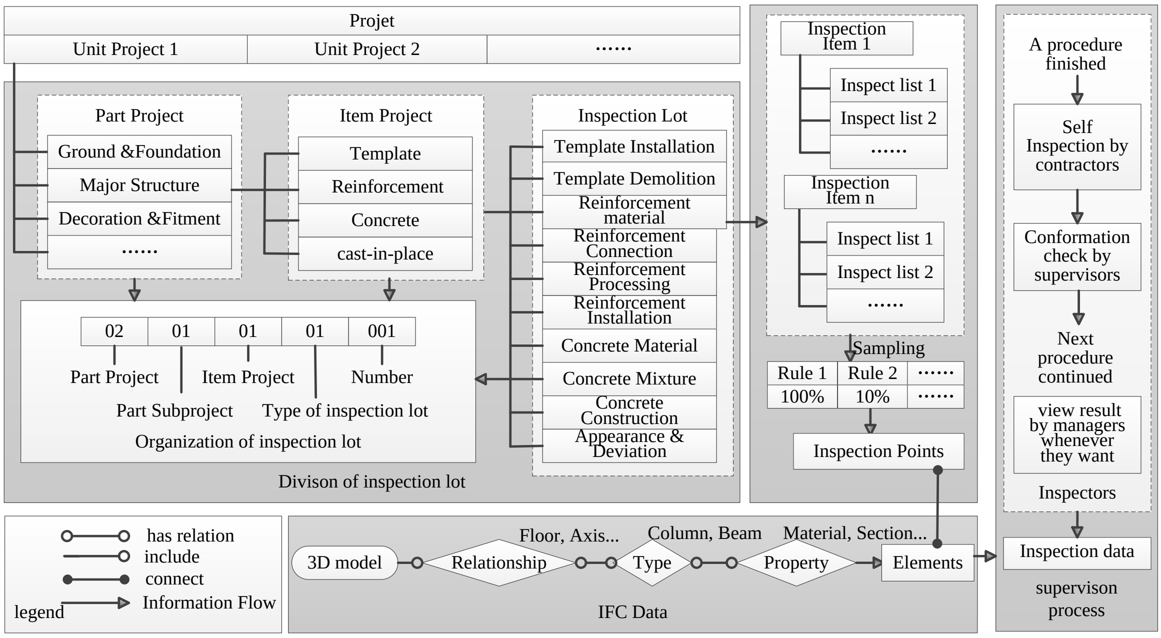

Figure 1. Information model for quality supervision based on BIM and related standards.

3.2. *Algorithm for automatically generating inspection items and points based on BIM and related standards*

IFC data includes not only the entity such as column, beam, plate, etc., but also the abstract concepts such as floor, axis, etc. Thus, based on the division rules of inspection lots, definition of inspection items and sampling rules of inspection points in the related standards, an algorithm is established for automatically generating inspection lots, items, and points based on BIM, as shown in Figure 2.

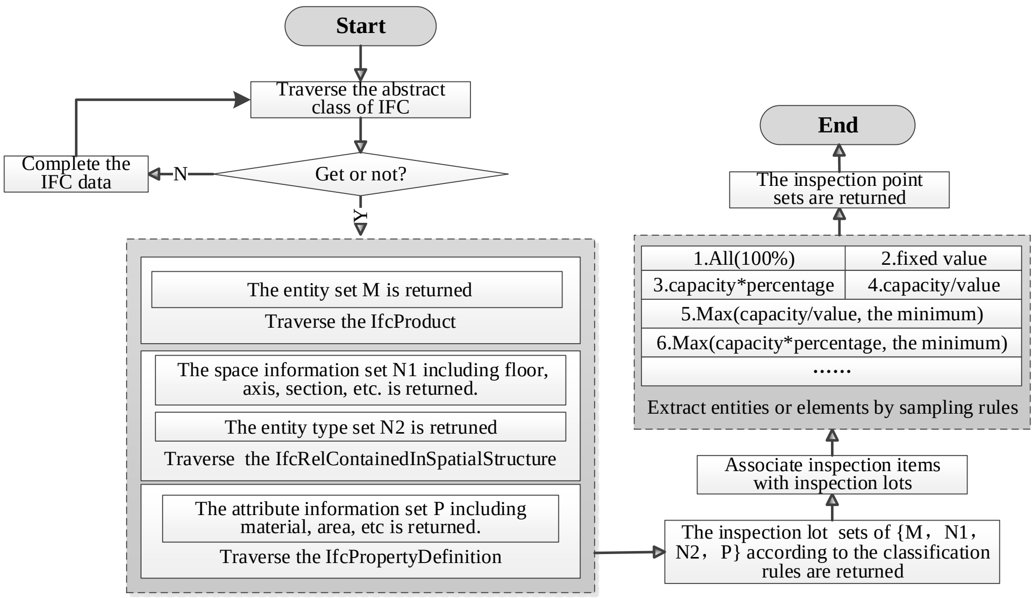

Figure 2. Algorithm for automatically generating inspection lots, items and points based on BIM and the related standards.

Firstly, IFC data are traversed to get the information of abstract class including Ifc product, IfcRel contained in spatial structure and Ifc property definition. Then, the set of entity, the space relationship, the entity type, and the attributive information are thus returned separately. Next, inspection lots are returned as {M, N1, N2, P} according to the classification rules and inspection items are associated with the results. Finally, inspection points are returned after sampling from inspection lots in accordance with each inspection item. The generated inspection lots, items and points will be stored in the database and used to support inspectors to view the inspection plan and get smart tips with mobile device.

4. Implementation of the approach based on BIMserver.org

The quality supervision system based on BIM has been developed to implement the key requirements. The system adopts B/S (Browser/Server) [7] architecture and can run on both a desktop browser and a mobile browser. BIMserver.org [8] was chosen to be the platform to manage the BIM data so as to greatly reduce the initial work of the implementation. Spring MVC [9] was used as the open source framework. MySQL [10] was chosen to be the database. After the completion of the system, a preliminary trial use was carried out.

4.1. *Architecture design*

BIMserver.org is an open source platform proposed by TNO of Netherlands. It supports the need to view and manage BIM data with IFC format [11]. The architecture of the system that uses the BIMserver.org is shown in Figure 3, in which the useful services of the BIMserver.org are called in the Spring MVC framework.

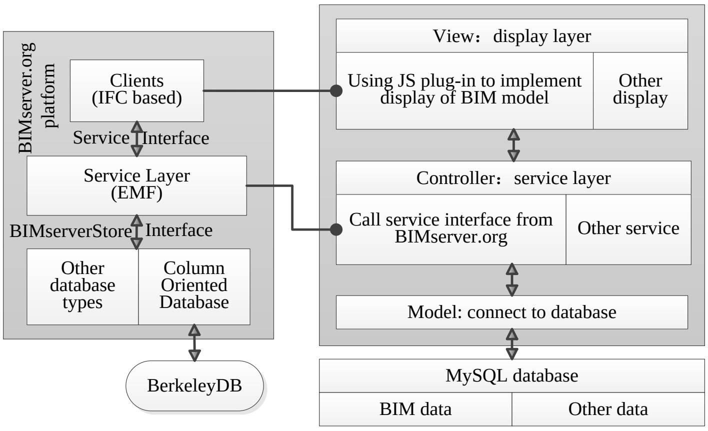

Figure 3. Architecture of quality supervision system based on BIM

4.2. *Application scenarios demonstration*

The system contains four categories of commands, i.e. project management, plan management, process management and result management. The typical application scenarios are explained briefly as follows.

By using the commands in the category of project management, a user from the contractor creates a project first, then uploads the relevant model file of IFC 2x3 [12, 13] or IFC 4 [14]. Then, the IFC files are automatically parsed and the 3D model is displayed in the browser. Users can view the project, model information, and operate the models by zooming, panning and rotating.

The commands in the category of plan management are used to automatically generate inspection lots, items and points based on the relevant standards. The inspection lots and items are organized as a tree-structure for a better index, and the inspection points are displayed as spheres on the model. For instance, the inspection lot of cast-in-place structure contains two principal and two general inspection items. Taking the first principal item as an example, which means, "the appearance has no serious defects", should be inspected on all components. Considering the construction sequence and inspection convenience, all columns and walls of the first floor should be inspected first. That is how inspection lots and points come from [15]. Figure 4 shows the main interface of the system in which the generation of inspection points of first inspection lot's first item is displayed. Compared with the traditional method of quality supervision, the generation of inspection lots, items and points automatically before construction avoids omission and negligence at the construction site. Besides, it is much easier for new inspectors to learn the current situation when some construction personnel changes.

By using the commands in the category of process management, inspectors click the generated inspection lots, items and points with mobile device to finish the self-inspection, conformation and rectification. They get smart tips and fill out customized forms for each inspection item specified by standards. The item can be basically divided into qualitative item and quantitative item. The former requires qualitative judgment or uploading documents. The latter requires inputting data. Figure 5 shows an example of filling out a self-inspection form corresponding to 5 columns and the qualitative item of "Appearance has no serious defects". After completing the judgment, uploading or inputting, the inspection result will be generated automatically and displayed on the model with different color. Compared with the traditional supervision process, without having to carry a lot of printed standards, inspectors can get smart tips of inspection lots, items, points and customized forms from the system with mobile device, so they can quickly complete every procedure and upload the inspection data to the server to automatically generate standard documents for a better management without second input. The system makes it possible to simplify and standardize the inspection process, avoid the disorder of data, and reduce the possibility of falsification without second input.

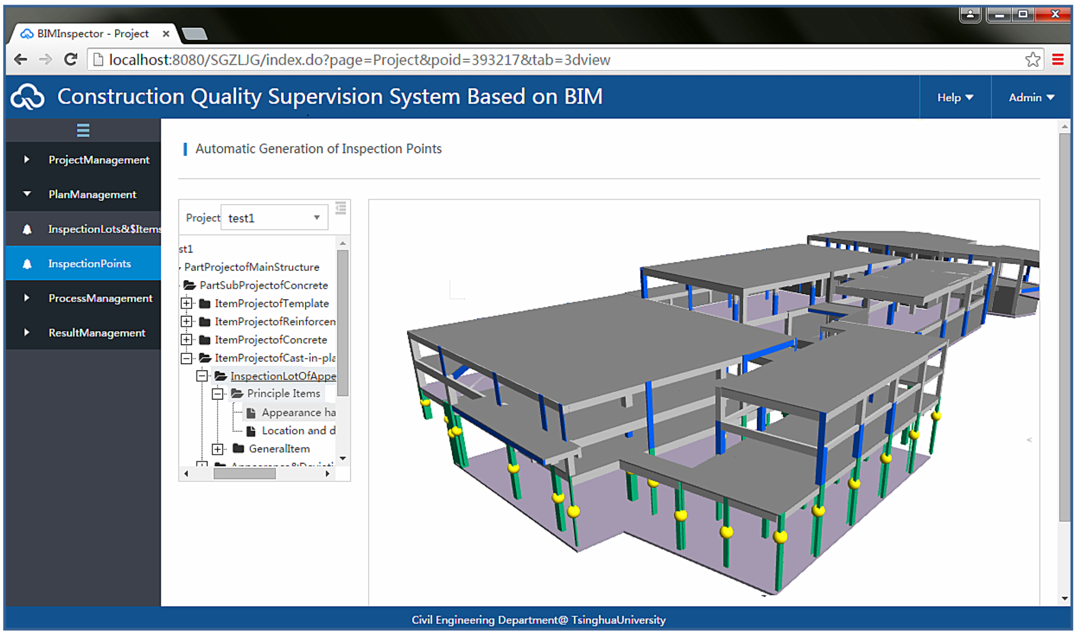

Figure 4. The generation of inspection points.

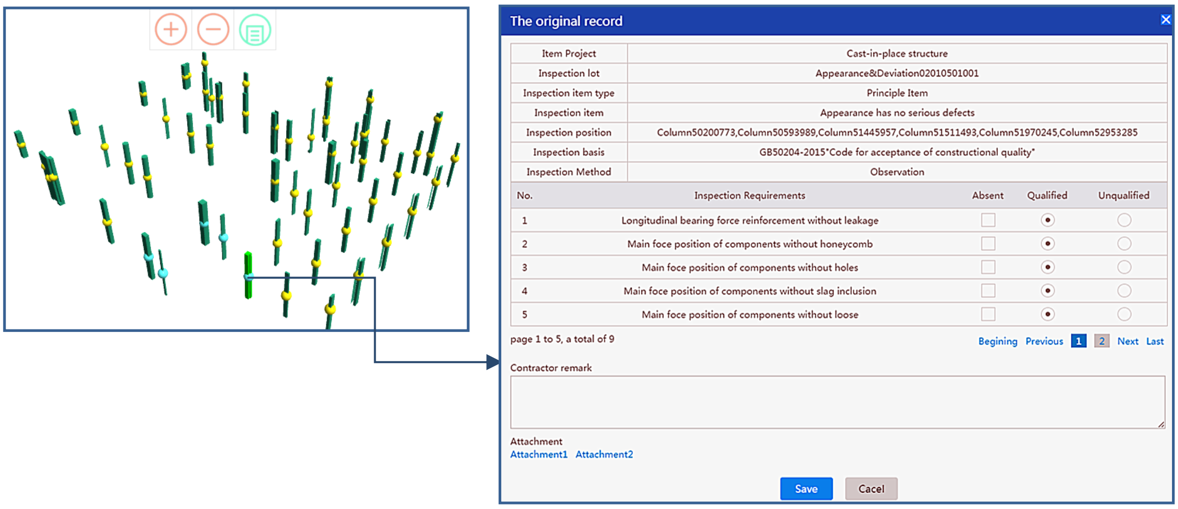

Figure 5. An example of filling out self-inspection record of "Appearance has no serious defects" item for 5 columns.

By using the commands in the category of result management, managers can view the uploaded data in time. They can check the inspection state by color of inspection points and other tags, conform the inspection progress with schedule diagram and check the relevant inspection reports. Compared with the traditional supervision process, managers can learn the situation without having to go to the site and learn more information before making decisions.

5. Conclusion and future work

In this paper, a system based on BIM was developed to improve the process of quality supervision. Firstly, the basic requirements analysis of the system was carried out. Then, an information model and an algorithm for automatically generating inspection lots, items and points based on BIM and related standards were established. Finally, the approach was implemented based on BIMserver.org and a preliminary trial use was carried out. It shows that the system makes it easier for inspectors to learn the inspection object intuitively and comprehensively before construction, more effective to filling out the customized forms without worrying about omission and negligence especially when some standards revised, and more convenient to input the data in the original records into computers without second input so as to reduce huge workload and data falsification.

Through the preliminary trial use of the system, it is understood that a big obstacle for users is to quickly identify the corresponding inspection points in BIM models when facing the inspection against a point in a real projects. This problem affects both the convenience and the efficiency of quality supervision. Luckily, indoor positioning technology has advanced rapidly in recent years, and some research outcomes have been applied to the construction site [16, 17 and 18]. In the future, the research will focus on integrating indoor positioning technology into the approach to help inspectors locate to the current inspection points and display them on model for a better management. Besides, the mobile side of this prototype system is a little complicated to the inspectors, so it is necessary to improve the interface to make it suitable for inspectors in the later work.

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An Investigation on Building Information Modeling Role in Industrialization of Buildings

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Abstract

The traditional methods of construction are not optimized from various aspects. This lack of efficiency throughout the lifetime of a project is evident during the planning, design, implementation and operation phases. To achieve ideal conditions in the construction industry to meet the annual housing demand on the one hand and manage the optimal conditions on the other hand, revisions need to be made in production of construction materials and products, design and implementation methods, construction technologies and incorporation of machinery. Meanwhile, industrialization of buildings could make great contributions to the housing demand where prefabrication and modular construction in factories and then assembling them within the workshop could increase the quality of project implementation and reduce the project time. The Building Information Modeling (BIM), which collects and documents all the required building information from the initial phase of planning till the operation phase during the entire lifecycle of the project in a data base, could be hired as an effective and efficient tool within the construction industry. Therefore, incorporation of BIM in industrialization of buildings could be used as a basis for investigation and assessment of construction projects. Also, it could improve the strengths and weaknesses of the industrialization process and addresses the design (integration) and construction (improved efficient management capability) phases. In this study, the role of Building Information Modeling (BIM) in industrialization of buildings and their interactions have been investigated.

Keywords: Building Information Modeling (BIM); Construction management; Industrialization of buildings

1. Introduction

Nowadays, traditional methods of housing construction do not meet the expectation of the society and considering the increased construction period, loss of materials and low quality performance, increased construction fees are observed. This construction process will lead to many challenges including [1]:

1. Inability to identify problematic issues due to having 2D layouts.
2. Delayed construction process due to problematic areas.
3. Lack of confidence in offsite construction due to presence of connections that necessitate onsite construction.
4. Duplication of efforts due to design flaws.
5. Increased required site monitoring to prevent conflicts between contractors.
6. Increased administrative burdens to obtain more information and change orders due to problematic areas.
7. First time installations from the contractors viewpoint.
8. Reduced efficiency for all parties involved during the project.

Consequently, the main characteristics of the construction industry at the moment involve inability in completion of the project according to the time layout and reduced profitability of this industry according to chronology [2]. Such features and characteristics stem from the difficulties and problems of the construction industry which are as follows [2]:

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1. No interaction between the design and construction teams
2. Short term thinking in the construction industry
3. Incomplete design information during construction
4. Poor management during construction process.

Two general approaches have been suggested by architects, engineers and the construction industry to overcome such problems. One approach includes industrialization of buildings where modular components, offsite prefabrication of components, quality control tests and finally transportation and assembly of such components on site would reduce the implementation time and improve the quality. The other approach recommends Building Information Modeling (BIM) as a common tool for every member of architectural, engineering and the construction industry societies (AEC) [3] and it provides integrated information regarding the entire building and a set of complete design documents and data stored in a database [4]. BIM could also pave the way for better interaction between the design team, client and contractors involved within the project and it could integrate the entire project life cycle including planning, design, implementation and operation in terms of procurement, sales and construction management. The better and more effective approach that can be hired to solve this problem is implementation of Building Information Modeling within the industrialization process of buildings to enjoy both the modeling and industrialization benefits and provision of more optimal conditions for construction projects within the housing arena.

1.1. *Definition of Industrial Buildings*

Different definitions have been given to industrialization of buildings. However, a comprehensive definition of industrialization states that in industrial method, building components are produced in the factory and then tested for various aspects of quality control and shipped to the workshop. In this method, the volume of construction operations at the workshop is reduced while the production rate is increased. In fact, industrialization of buildings is a precise process that considers the elements of time management, cost and quality standards for mass production [5]. Although industrialization, according to this definition, has countless benefits in mass production, it has great benefits for small scale construction projects. It is good to mention that mass production should not be interpreted as high-rise construction but should be investigated and evaluated separately in high-rise, mid-rise and low-rise construction [6].

1.2. *Building Information Modeling Definition*

Since the emergence of Building Information Modeling (BIM) as a new phenomenon in the construction industry, there has been no consensus on its definition and everyone has their own definition based on their viewpoint [7]: For some, BIM is a software application; for others, it is a process of design and documentation of building information which requires implementation of new policies, contracts, and relationships amongst project stakeholders.

Other definitions of BIM include: object-oriented modeling, project modeling, virtual design and construction, virtual prototyping, integrated project database [8]. In another definition, BIM is defined as a digital representation of physical and functional characteristics of a facility. Also, it is referred to as a shared reference of knowledge for formation of an information center and a reliable basis for decision-making during life cycle of a building from beginning to end [9].

In another definition, BIM has been defined as simulation of construction projects within virtual environments. By using the BIM technology, an accurate virtual model of a building, as a known building information model, is digitally made. Upon completion, the building information model including precise geometry and relevant data needed to support the design, procurement, construction and construction activities will be provided for implementation of construction [10].

2. Industrialization of Buildings and the Challenges ahead

Nowadays, incorporation of new technologies along with moving towards industrialization has revolutionized all aspects of human life. The construction industry has not violated this trend and has been subject to changes and developments. Yet, much of the implementation of residential buildings is performed traditionally. The roots of this problem need to be diagnosed. The question is why industrial implementation of buildings has not gained popularity amongst the public. Perhaps misunderstanding the concept of industrialization has led to this problem.

Industrialization of buildings is recognized as a fundamental and appropriate method to retrofit buildings against natural disasters like floods, earthquakes and wind. Also, incorporation of new construction materials particularly conventional insulators common in industrialization process is known as a suitable solution to avoid energy losses [2].

Moreover, assessment of new construction technologies in terms of architecture and energy, debate over the advantages and limitations of construction technologies in industrialization of buildings [11], provision of required solutions to spread such mechanisms, studying the feasibility of localization, ensuring its compatibility with common construction patterns and finally spread of industrialization through provision of necessary training to ensure manufacturing quality and implementation of different systems is essential [12]. This could not be achieved without considering the challenges facing the deployment of new technologies [13]. Hence, application of dynamic management system approaches and industrialization technologies in construction projects from the perspective of project management role in optimal implementation of activities using new materials in manufacturing industry is necessary [14]. Incorporation of industrial systems of construction with an emphasis on the concept of sustainable development and provision of industrial construction systems is crucial in three scales namely high-rise, mid-rise and low-rise buildings. Accordingly, application of new technologies is believed to be in line with sustainable developments of the country in terms of economic, social, and ecological issues [6].

2.1. *Advantages of Building Industrialization*

Industrialization means modularity, observance of the project triangle, dynamism and flexibility, energy efficiency, continuity in the process, existence of a comprehensive system of collecting and spreading information, existence of training and finally paying attention to transportation production. Some of the main features of industrialization are listed as follows:

1. Avoiding the use of traditional and manual methods of construction
2. Serial and mass production of a prototype using repeating mass units (repeating)
3. Application of prefabricated members under controlled conditions and assembly of members in the workshop
4. Reduced energy and material waste during construction process [15].

2.2. *Importance of Building Industrialization*

At the moment, no technical or scientific barriers exist ahead of developers, industrial construction technologies are available for everyone and experts are completely familiar with this industry. Nevertheless, the only missing factor is shortage of supplies in industrial production. In industrialization process, construction time can be reduced and quality control will be more precise and eventually, a building with a higher service life will be obtained.

3. Significance and Characteristics of BIM

BIM is recognized as one of the most promising approaches in architecture, engineering and construction industries. Incorporation of BIM would yield more precise visual models of a structure and consequently, such models will support schemes that provide better analysis and control of manual processes. The moment that such generated computer models entail accurate geometric information that supports construction business, they are treated as completed models [10].

3.1. *Characteristics and Features of Building Information Modeling*

BIM technology is considered as one of the newest and most efficient means of information management that is currently hired by construction companies as a competitive tool to enhance project management capabilities. In this method, the components of the building are modeled and the characteristics of each dimension will be recorded. This data could be used as a common data base for the design, construction and project management teams [10].

1. N-dimensional modeling: these models include 3D modeling, time as the fourth dimension, cost as the fifth dimension and maintenance as the sixth dimension.
2. Design error detector using the "Clash Detection" capability.
3. Integration of design and project management.
4. Quick and precise access to management reports.
5. Integrated management of changes.
6. Simplified cost and time management.
7. Documentation and archiving the project information, and
8. Object-oriented modeling: in this process, each object is modeled once only.

4. The Role of BIM in Building Industrialization

BIM requires many functions to model the life cycle of buildings to provide a basis for new building potentials and provides new roles and interactions between the project team members. The moment BIM becomes compatible well enough, a more uniform design and construction process will be provided that could lead to increased quality and reduced time and costs of the final structure [16].

Industrialization is believed to be equal to modularization and it is expected that building components should be prefabricated in factories and be assembled in job site that necessitates the prefabrication of components in the factory so that no problem occurs during the construction phase. Meanwhile, maximum benefits could be obtained from BIM which are as follows:

1. Similar Design and As-built Construction

One of the biggest advantages of BIM is as-built construction. In this procedure, the design process is based on physical shape and real dimensions of the building. Hence, this plan is precisely applicable and results in the lowest dimensional tolerance.

2. Large-scale and Complex Projects

In large-scale projects, the volume of work and investment is so high that necessitates precise cost estimations prior to the start of the project. Incorporation of BIM has countless benefits including complex designs, detailed and optimized measurements and cost estimation, project management and coordination between the parties involved, speed in construction and reduced costs. In order to justify the increased costs of industrialization process compared to those of traditional ones, either large scale projects or mass production must be practiced.

3. The Relationship between Factors

Application of BIM would make the final design of the building understandable and therefore, the concept of design will ideally be exposed to other factors. First of all, the client is informed with the final design and then will optimize it according to their anticipations. The executer knows which methods to choose to conduct the construction procedure. The supervisor would also be able to the compliance of design and construction. The project manager would be able to choose the best methods of allocation of resources and timing for the project and eventually, the presale customer will have a clear picture of the purchased apartment. All such advantages stem from the fact that the final model is available and there would be no need for interpretation or visualization.

4. Optimized Project Management

BIM is recognized as a precious tool for project managers. The final model of the project could be used as an input for software like Autodesk Navisworks, Tekla BIMsight, Bentley Navigator and various stages of the project could be scheduled. Also, estimation of the labor force and materials would be easier. The construction stages will be available in detail. The location of cranes, depot materials, scaffolds and temporary facilities could be predicted. Time schedule is of great importance in industrialization process. Therefore, BIM could be a great means of allocation of materials, manpower and machinery to the ongoing projects.

5. Following the Project during Construction

Smartphones and tablets play an important role in communication and information transfer. Thus, BIM could be used as an effective tool to have access to your information [17]. One could carry also take the building model to the project site and share and discuss the required information with contractors and other parties involved.

6. Construction Phasing

Incorporation of BIM could picture all the possible forms of the project over time. There could be a possibility that your project was divided into phases. Some parts of the current structure need to be demolished and reconstructed. Yet, a development plan needs to be considered for the upcoming years. Also, building modeling could gather the entire construction phases in one place and could choose the best and most optimum plan for the project. Besides, it would give you a complete insight of the existing structure, the parts that need to be demolished and reconstructed along with the final design development of the project.

7. Faster Execution of the Project

Since an appropriate insight of the entire project steps is available, conflicts and problems are solved prior of the project and redesigning has been conducted as well, the executer knows how to execute the project. The client knows his expectations. Also, construction phase would be performed with minimal delay and problems. Consequently, investment and construction period will be minimized.

8. Component Interference Elimination

In industrialization process, most of the components, parts and panels are prefabricated in the factory and installed at job site. In case of interference between the components, the problem diagnosis possibility will be challenged. As a solution, during the modeling process, the building will be virtually designed and tested thoroughly. Hence, component interferences are solved and the structure will be redesigned again.

9. Reduced Duplication and Costs

During the modeling process, it would be possible to model a wall several times and demolish it; it would be complimentary and quick. Any duplication of efforts will be conducted virtually and there would be no need to take the hammer and destroy one's own property.

All direct or indirect BIM advantages are hired to reduce the final cost of the project. Hence, the structure is built with minimum material loss, demolition and delay.

10. Dynamic Design and Rapid Revisions without Error

Perhaps the biggest advantage of BIM in the design phase would be the dynamic nature of the modeling process because building models have the capability to adapt themselves with the changes made to the other portions of the structure. If revisions need to be made to the architecture or facilities of the model, this could be achieved via a few simple commands to synchronize the model with the changes. This issue is probable during the construction.

In two-dimensional CAD design, design revisions could be costly and time-consuming because the designs are not performed on a common platform. Thus, all the relevant parts need to be revised as well and the possibility of component interference increases. The later such revisions are made, the higher the costs will grow and delays will occur.

However, any revision in BIM, even in different sectors such as architectural design, construction, utilities and power, would result in changes in other relevant components. Moreover, the revisions are very quick and the possibility of component interference will be eliminated as the designs are performed on a common platform.

11. Cost Estimation of Materials

Since the final model is available, the cement volume, weight of rebars, number of tiles, switches, and the pipes could be calculated in minutes and consequently, the cost estimation process will no longer be a difficult and time-consuming task. Set the price for each item and estimate the final cost of the project. Try to have a complete list of vendors and Executers and do not be afraid of changes. Any possible change within the model would update the cost estimation automatically.

12. Precise Calculations

One of the advantages of BIM includes provision of precise and regular calculations of the different portions of the structure. The building model will be used as an input for structural engineering software and its response to different loading conditions (live, dead, earthquake, wind, snow, etc.) will be analyzed. Its weak points will be identified and strengthened. Incorporation of BIM facilitates the wall computation and overall energy analysis of the structure. This is achieved through separation of each room or space, the air required, channel size and its tube diameters. Also, the required light will be calculated. The electricity demand and its coincidence factor are also determined.

13. Data Exchange with other Software

One of the most important features of modeling with BIM, the possibility of importing the model into other software for any required operation. The model could be added to software like Tekla, SAP, Etabs, Robot, and etc. to perform the structural analysis and then, such analysis could be used to update the entire model of the building. This option could be used in all aspects of design and could enhance accuracy and speed. Also, the building model could be imported in visualization software and it could provide videos and photos of the actual project.

5. Conclusions and Recommendations

This article discusses the application of BIM in industrialization of buildings and its advantages to the construction business. In this regard, three factors namely time, cost and quality are recognized as the main and effective factors in construction projects. Therefore, incorporation of BIM in building industrialization has the following benefits:

1. As built construction will be practiced that could eliminate the component interference within the project and hence, it could reduce the duplication of efforts and costs.
2. Application of BIM would facilitate the communication between contractors, client, engineer, control system and subcontractors and the time that should be spent to resolve the conflicts between the abovementioned parties will be dedicated to the project.
3. Incorporation of software like Navisworks, Navigator, BIMsight in industrialization process would prepare a time schedule for different stages of the project. In case required, the development scheme for the upcoming years could be provided through phasing the construction process and therefore, provide optimal project management.
4. Building industrialization would reduce the construction period. Yet, since BIM provides a good insight of the project, the project could be conducted without any pause and with minimum construction problems.

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Enhancing Facility Management through BIM 6D

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Abstract

BIM has been widely adopted by the construction sector, though Facility Management (FM) is still based on a variety of disparate FM systems. The operational phase requires comprehensive set of well-structured information regarding the building asset. Therefore, a BIM model filled with the multifarious information from the pre-use phase ought to be exploited through its integration with existing FM systems. This paper aims to appreciate the contribution of BIM in optimizing the processes conducted conventionally within the FM practice. The importance of sustained information flow for the efficient operational stage is a pre-requisite of the further discussion. The exploration of FM application areas for BIM-enabled processes is aimed to depict the potential of the BIM for FM concept. By elaborating on the existing challenges concerning the shift from traditional FM processes to new BIM-based approach the outstanding problems are realized. On these grounds advice is provided. The study focuses mainly on new investments, where information management must be sustained from the project inception until the current operational stage. The paper proves the potential of BIM for the optimization of FM practices, presenting a wide range of application areas followed by tangible benefits for the building performance across its life-cycle. Identified barriers are assumed to be mitigated by diligent implementation of provided recommendations. It is concluded that BIM-based FM processes have the potential to shed a new light not only on the FM sector itself but on the perception of the whole industry being based on the collaborative approach towards delivery of the intelligent facilities. Nevertheless, such results demand profound cultural changes within the construction sector, with the FM appreciation as a starting point.

Keywords: BIM-enabled processes, BIM 6D, Facility Management.

1. Introduction

Traditionally Facilities Management (FM) is recognized as a "non-core" part of the construction sector, focused mainly on supportive services with no real business value. Due to existing inefficiencies the FM importance is far from being appreciated [31].

FM constitutes for over 80% of the total project cost and hence its imperativeness ought to be acknowledged [6]. Conventionally the handover process takes up to several weeks for information to be collected and entered into FM systems [32]. The performance gap existing in FM practices unable to reap the benefits resulting from the efficient post-construction stage. Nonetheless, the FM sector is lagging behind construction and design with BIM implementation whilst the opportunities for leveraging this concept for the operational stage are compelling [14].

The paper starts with explanation of information logistics across the building asset life-cycle assumed to be a pre-requisite for further elaboration on the topic. FM application areas for BIM-enabled processes are presented afterwards. Subsequently, challenges and implications that hinder the potential of BIM for FM are depicted followed by recommendations for fully utilizing the discussed concept's benefits.

2. Logistics of information across the building asset life-cycle

Following [24], [22] sustained flow of information throughout a building life-cycle is crucial and should be deemed a primary objective for each construction endeavor from its beginning to the current operation stage. In

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this paper emphasis is put on building life-cycle rather than the construction project itself. Meaning that, the latter must be perceived as a holistic approach driven by the shift to final-product-oriented construction settings, aimed on procuring more efficient facilities.

2.1. *Importance of seamless information flow*

Maintainability of the asset refers to the business aspect of a construction investment and is oriented on attaining an optimum performance for the building across its life span [4]. Therefore, it is credible that strategic decisions concerning managing facilities must be made in advance as a pre-requisite for achieving expected business profitability afterwards. It cannot be denied that a significant upturn of business returns is in direct proportion to the increased efficiency of O&M processes [5]. The latter, in turn, is dependent upon the quality of information derived from the project delivery.

2.2. *Managing information efficiency*

Parsanezhad [24] sets out that information management in order to be efficient must be based on sustained collection, analysis and flow of information across the multidisciplinary environment throughout the life-cycle of the building asset. Such a holistic approach is defined by the buildingSMART alliance [3], as a “business process for generating and leveraging building data to design, construct and operate the building during its lifecycle”. As it is argued Building Information Modeling (BIM) is not a new technology that has recently emerged on the market being forced by private vendors in order to replace current FM systems. Furthermore, it is a business process that encourages all stakeholders to be proactively engaged in the project delivery. Building Information Model (BIM model) is the output of this process which holds building data from its inception till the current operational phase. Data generated during the construction project delivery process is extracted from BIM model directly to non-proprietary International Foundation Class (IFC) file formats [22].

2.3. *Bridging the gap for sustained logistics of information*

Aforementioned arguments imply that in order to assure effective flow of information the consideration of construction project delivery as a process composed of the three main phases is essential. O&M stage ought to be treated, at least, equally to construction and design stages. Integrated approach to project delivery through BIM is a warrant of sustained flow of information. Developing awareness of above mentioned principles is a key to fully-realizing the benefits of implementing BIM. Since it is only matter of time until BIM becomes obligatory for all projects, BIM-resistant attitude will simply imply dip in the market share. The authors treat this knowledge as a pre-requisite for appreciating other application areas for BIM 6D and allowing further development of this yet fertile field.

3. Realizing the potential of BIM for FM

Having acknowledged that first and foremost BIM must be perceived as a shared knowledge platform for the building information that enhances decision-making during the asset life-cycle, subsequent application areas are to be depicted in this section. BIM 6D (sixth-dimensional Building Information Modeling) refers to the post-construction phase (O&M) of the building, however for many 6D stands for ‘sustainability’ mostly [24]. Indeed both definitions are correct since BIM 6D is primarily oriented to improve FM practices efficiency, which apparently overlaps with the life-cycle performance of the building, hence its sustainability.

3.1. *BIM in FM – application areas*

Fields of FM practices where BIM-based applications are successfully implemented are linked to the corresponding case studies presented in Table 1. All functionalities mentioned below are endorsed and further developed by the authors Becerik-Gerber et al. [4]; Love et al.[16]; Volk et al. [29].

Table 1. FM related BIM application areas identified in the real-life case studies

Application area \ Case study (ID nr)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Mobile localization of building resources							▪		▪	▪
Digital asset with real-time data access	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪
Space management		▪	▪							▪
Renovation/retrofit planning and feasibility studies	▪	▪								▪
Maintainability studies	▪	▪	▪							▪
Energy analysis and control		▪	▪							
Safety/emergency management		▪			▪					

Legend:

(1) Sabol [26]; (2) Aryaici, Onyenobi and Egbu [2]; (3) Neelapala and Lockheed [21]; (4) Codinhoto and Kiviniemi [5]; (5) Wang et al. [31]; (6) Orr et al. [22]; (7) Lin, Su and Chen [12]; (8) Su, Lee and Lin [27]; (9) Costin et al. [6]; (10) Fillingham, Malone and Gulliver [10].

There is no doubt that BIM 6D could bring revolutionary change for FM practices. Nonetheless, the authors believe that the full potential of BIM 6D can be realized only when currently available application areas are verified.

3.1.1. Mobile localization of building resources

Building components (equipment, materials etc.) must be located by the FM personnel on daily basis. Prompt reaction is critical for efficient problem detection and its resolution [4]. Conventionally when performing daily procedures FM personnel rely on a paper-based facility map and subjective judgment based on experience [9]. In many cases such approach is not effective enough (e.g. not readily visible places) or even worse - dangerous, since it might put others at stake (e.g. emergency). Nonetheless, productivity, safety and security could be optimized by the real-time resource location through integration of a BIM model and Radio Frequency Identification (RFID) technology [6]. Lin, Su and Chen [12] shed a new light on this matter by proposing even better value for money through the barcode-based system.

3.1.2. Digital asset with real-time data access

Following Paranezhad [24], “information” is a processed data, put in the relevant context. IFC files collect massive building data, whereas COBie spreadsheet selects only these adding value for O&M phase and structures them into context-based information. FM practitioners should be heading towards knowledge-based solutions, achieving subsequent step of this sequence. In order to satisfy this need Motawa and Almarshad [19] suggest knowledge-based system supporting O&M activities by enhancing BIM capabilities. Case-Based Reasoning (CBR) is a technique that enables the asset owners to learn from their past experience and hence avoid ineffective maintenance. The latter could be either preventive/predictive (planned) or reactive/corrective (repair). Though, reactive maintenance is more common and could be even four times more expensive than planned one for the same repair [14]. For efficient preparation of maintenance schedules for both preventive and corrective maintenance Motamendi, Hammad and Asen [18] come up with failure-cause detection patterns based on the knowledge-assisted and BIM-enabled visual analytics.

3.1.3. Space management

First and foremost, it is paramount for asset owners to understand the business operations taking place within the building asset. Such knowledge is a pre-requisite for adequate space classification, adjustment of space standards and eventually appropriate departmental allocations. The importance of BIM in this matter is undisputable since it enables space planners to exploit its visualization and coordination capabilities by streamlining the move process, forecast space requirements and facilitating space analysis [4].

3.1.4. Renovation/retrofit planning and feasibility

Depending upon the scale of the work and apparently contractual relationship, FM team quite often coordinates noncapital construction as well. BIM provides a profound basis for planning and feasibility studies with historical database of the existing building used as a reference for the cost estimation of the planned work. As the availability of a BIM model warrants a visual information to the designated structures then remodeling, refurbishment or demolishing should be performed seamlessly [29].

3.1.5. Maintainability studies

Maintainability is referred to in the first section of the paper, where the imperativeness of collaboration approach throughout the project delivery is highlighted. The BIM-enabled effective utilization of information is a warrant of sustained performance with a minimized upkeep costs during the building life span [24]. As suggested by Becerik et al. [4] BIM-based maintainability studies are concerned with the following areas: accessibility, sustainability of materials and preventive maintenance. BIM model enables FM staff to perform automated maintainability studies oriented towards operational stage assessment.

3.1.6. Energy analysis and control

UK Green Building Council [28] alarms that building operations account for around 40% of global energy consumption and 30% of carbon greenhouse gas emissions. Anton and Diaz [1] and Motawa and Carter [20] also agree upon the pivotal importance of building energy performance for procuring sustained investments. Though, also suggest that current energy consumption systems are not fully integrated due to the complexity of energy analysis and hence the need for a more efficient approach for energy simulation is stressed on. Motawa and Carter [20] come up with a sustainable BIM-based system that enables energy managers to perform complex energy evaluation efficiently by integrating energy-related information across the building asset life-cycle. Becerik-Gerber et al. [4] acknowledge the need for systems integrity.

3.1.7. Safety/emergency management

Cox and Terry [7] underline that within BIM, the critical and sensitive data is secured and accessible only for those who need it. This implies an improvement in safety, though it must be noted that such solution leaves also room for information abuse when being given an access to. Therefore, the asset owners must ensure that BIM-data protection systems are established. During emergencies FM personnel is foremost liable of mitigating life-threatening risks and facilitating the work for emergency units. In order to react promptly and adequately it is critical to have relevant data in place, organized in a logical and accessible way. Detailed information could be provided even before rescue units' arrival and hence professionals could develop a solution for a response and recovery more effectively. Wang et al. [30] create BIM-based emergency system that provides real-time two-way information flow, creating evacuation routes based on the user's location.

3.2. *Pursuing the competitive advantage*

There is no doubt that the full potential of BIM 6D has not been explored yet. Nonetheless, the authors believe that aforementioned application areas give enough reason to appreciate the importance of this emergent concept. The paper focuses on defining the most relevant technical benefits for enhancing FM practices, though it must be underlined that all conventional inefficiencies most often result in cost, time and quality deteriorations.

4. Fully utilizing BIM 6D capabilities

Despite BIM has already been utilized during design and construction stages [11], the previously discussed FM functionalities have not been widely applied yet. Apparently there are barriers and challenges responsible for the state of affairs, therefore remedies for them ought to be addressed.

4.1. *Problems encountered*

Authors collectively acknowledge the existence of challenges and implications that delay the BIM implementation in FM [4], [8], [14], [29], [30]. Based on the literature and practitioners' view the problems reported below are deemed most influential.

Table 2. Challenges and barriers of BIM 6D implementation process

Challenge/Barrier: Unclear roles and responsibilities regarding BIM model; Data requirements – level of development (LOD) needed; FMs role is underestimated; Lack of FMs input during the early stages of the project delivery process; Information exchange and transfer – interoperability concern; Lack of BIM knowledge/experience among the FM practitioners; Change-resistant attitude, lack of cases proving the positive business value.

4.2. *Action plan for leveraging BIM in FM*

The approach towards the fully employing BIM 6D potential envisaged in the paper is two-fold. Having elaborated on application areas that enhance FM practices, the key step is to plan and manage against known pitfalls that may hinder the sustainable manner of implementation process. Otherwise the expected benefits may not arise.

4.2.1. Plan and manage the implementation process

First and foremost, BIM potential must be actively managed for its full utilization. Therefore, in order to tackle the organization-wide uncertainty/reluctance towards innovation there should be a strategic implementation plan in place [16]. Becerik-Gerber et al. [4] suggest that leveraging the potential of BIM 6D requires a visionary owner who would lead the process from the early stages of the project delivery. Though, the authors do not fully agree since the support from the BIM manager could be a solution for the inexperienced owner too.

4.2.2. Collaborative approach towards Facilities Design

It is argued that the integration of the asset owner/end-user and facility manager has pivotal implications for O&M phase, provided that is made at the early stages of the project delivery [32]. Since the FM professionals are valuable source of information concerning end-users' expectations then their input in shaping the owner's requirements is beneficial for both sides [24]. The level of detail of the BIM model can be established effectively on the grounds of this relationship. The LOD (level of development) must reflect business needs and in many cases lower detail may be sufficient for FM team [13].

4.2.3. Standardize the format of information exchange and transfer

The BIM concept conveys certain principles that shape an attitude towards building asset life-cycle being strongly supported by technological advancements. The clue of BIM 6D is to integrate BIM model with existing FM software packages and hence assure a seamless flow of information with BIM model as a knowledge-based platform. Though, due to the magnitude of this change the relevant software applications are still being implemented in isolation, deepening the interoperability issue [30]. Diversity of private vendors trying to push their products on the market causes a great confusion within the industry and hence it is paramount for the BIM community to reinforce efforts on the development of nonproprietary methods. Additionally, as reported in the literature it is still unclear which facility data when and how ought to be transferred [30]. COBie as a simplified subset of IFC format was created to tackle these inefficiencies, though the practitioners still find some space for further improvements [17].

A cloud approach towards interoperability enhancement is a common topic in the literature, being deemed the right direction for future development. As proposed by Redmond et al. [25] the industry should focus on developing web-based BIM exchanges using the cloud platform incorporating both IFCs and SML (Simple Markup Language) files.

5. Conclusion

The authors aim to determine the extent to which BIM's utilization during operational stage is a warrant for more efficient and effective conduct of FM processes. This is achieved by presenting the application areas of BIM-enabled processes, bearing in mind the seamless information flow as a pre-requisite. Furthermore, existing challenges and barriers that hinder the successful employment and application of BIM 6D are identified and a solution in the form of an action plan is provided.

Understanding conventional FM practices allows establishing a performance gap, primarily attributed to inefficiencies in the information management across the building asset lifecycle and lack of collaborative attitude among actors within the industry. Furthermore, BIM as a collaborative process that facilitates the sustained logistics of information is introduced as viable way of bridging the gap identified earlier. Developing awareness of FM application areas for BIM-enabled processes is the first step towards appreciating BIM 6D potential.

By presenting explicit evidence of BIM applicability for FM practices the paper introduces researchers and foremost practitioners to the clear concept potential. Future work should focus on experimenting through larger number of case studies to ensure and verify the construction industry of the practical applicability and feasibility of implementing BIM 6D.

The main barriers that are difficult to be dealt with are cultural changes and interoperability issue. The latter one is continually being developed and hence it is believed that the technological advancements (e.g. cloud based applications) together with governmental efforts (e.g. the BIM development communities) are about to tackle it soon. Nevertheless, the authors claim that it is no longer lack of technological solutions that prevents the sector from implementing BIM-based revolution, it is the construction industry's inability to cooperate. However, the industry is continually evolving being led by BIM development hence the authors believe that all the aforementioned issues could be gradually diminished and eventually solved.

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Acceptance of Construction Scheduling Visualizations: Bar-charts, Flowline-charts, or Perhaps BIM?

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Abstract

Four-dimensional Building Information Modelling is widely viewed as the next evolutionary step in construction scheduling. Linking scheduling information to parametric object models is believed to assist a more intuitive understanding of what is to be built when. We explore how 4D BIM, as a new method of visualization, compares to other pre-existing forms of visualization like bar- and flowline- charts. Based on a series of individual and focus group interviews, this paper reports construction professionals' perceptions of the utility of the different visualization methods. Simultaneously exposed to three types of scheduling of the same building, construction professionals evaluated their ease of use and usefulness. This was done based on the Technology Acceptance Model, which explains how individuals develop an intention to use technology. Based on this work we found the three scheduling methods having strengths and weaknesses. Gantt provides the simplicity and responsiveness required for the day-to-day communication in projects, and was perceived as the easiest to use. Flowline was perceived as less intuitive; however, some argued that it provides a better overview when many different work activities need to be run concurrently. 4D BIM has the clarity required for conveying the bigger picture, yet was perceived as most useful for early project stages. Our contribution to the body of literature is that we compare the technology acceptance of new and existing scheduling methods in order to unearth their complementary roles. This work is important for managers deciding on a combination of planning tools, enabling them to better run their projects.

Keywords: 4D BIM, Flowline chart, Ganttt chart, construction management, Technology Acceptance Model.

1. Introduction

The Nordic countries are among the global leaders in Building Information Modelling (BIM) adoption and implementation [1]. Norway's governmental construction clients have mandated BIM use in their projects since 2007 [1]. Thus, most large construction firms in Norway have experience from working based on BIM. Initially one might expect that Norwegian construction professionals would readily apply BIM technology to support management tasks in their projects. However, it appears that even in the countries most advanced BIM project, schedules linking time with solid object modelling are not yet actively used [2]. In fact, the wide availability of BIM models did not significantly change the way in which project schedules are prepared. Classical Gantt, Critical Path (CPM), and flow-line charts continue to be the preferred tools for construction managers. The struggle project managers have with evaluating how 3D/4D technology can be efficiently applied in projects has been reported in literature [3]. Nonetheless, 4D BIM is widely viewed as an important technique for eliminating waste and increasing value for the customer in construction projects. Is the Norwegian construction industry, by not using 4D BIM, missing out on some of the advantages BIM technology has to offer [4, 5]. Alternatively, are there good reasons for practitioners to continue using the classical schedule visualizations in their day-to-day work? Are the scheduling methods complementary and used for planning different aspects of a construction project? These questions motivated the article presented here.

Considering that moving towards using 4D BIM is a 'technochange' influencing organizational work at several dimensions, then it may simply not be easy to use 4D BIM [6]. The term 'technochange' refers to situations where deploying new technology significantly affects organizational life. This is the case for the application of 4D BIM since it is influenced by and influences the features of the industry, projects, and people involved [7]. A risk involved in technochange is that people simply will not use the new technology and related processes. Scholars' report that especially 'off-the-shelf' software, developed by technical teams not familiar with the characteristics of the organizational context, is likely to be resisted [6].

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Whether individuals accept or resist using a new technology depends on whether they perceive it to be beneficial or detrimental for doing their jobs. It is important that there exists a perceived relative advantage of using a new technology over the current solution it replaces [8].

In this article, we focus construction teams' technology acceptance of 4D BIM when compared to Gantt and Flowline [9]. More specifically, we focus on the extent to which a construction team working in a Norwegian project, where different schedule tools were applied, accepted the technology. We contribute thereby to the discussion of whether and how users find Gantt, Flowline and 4D BIM technology useful and easy to use for doing their jobs. This work is important because using IT-technology on construction sites is virtually impossible without users accepting the new technology [10]. Many organizations remain skeptical about changing established work practices in response to new information systems [11]. Our research question is: *How useful and easy to use are different schedule visualization methods for construction site teams?*

To answer the research question we conducted a case study in an ongoing joint apartment and office project in Oslo where Gantt, Flowline and 4D BIM were used to schedule the works. A series of semi-structured interviews with individual construction managers, construction workers, and site engineers has been conducted to gain an understanding of how the technology has been accepted by the people using it. The theoretical approach supporting the analysis in this article is the so-called Technology Acceptance Model (TAM) [12]. The intended contribution of this article is twofold: First, we argue that research taking a TAM perspective to understand construction teams' acceptance of 4D BIM adds to the understanding of the potential that lies within its deployment. Second, construction managements' awareness that construction crews may or may not accept an on-site use of Gantt, Flowline and/or 4D BIM in specific situations can be increased by this study. The article is structured as follows: first, the Technology Acceptance Model (TAM) guiding our analysis is introduced. Second, the "joint apartment and office" project case is introduced. Third, the findings of the case study are presented based on TAM. Fourth, the discussion of the technology acceptance is presented. Last, we present the conclusions of our work and answer the research question.

2. Theoretical lens

There exists a broad spectrum of theoretical models explaining technology adoption and acceptance (e.g. Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology, Actor Network Theory, and Diffusion of Innovations). These theories also inform construction informatics and management research [13] (Merschbrock and Munkvold, 2012). The technology acceptance model (TAM) has informed research on the user acceptance of building management systems as well as research on individual beliefs about the outcomes of BIM use [14, 15]. A graphical depiction of TAM can be found in figure 1. The model depicted in figure 1 builds on the original TAM model introduced by Davis [9]. and the theoretical extensions (e.g. TAM2) suggested by Venkatesh and Davis [16]. Diverging from the original TAM and TAM2 models, the construct names 'intention to use' and 'usage behavior' have been rep laced with 'behavioral intention to use' and 'actual system use' respectively. This has been done in accordance with what has been proposed by Venkatesh et al.[17].

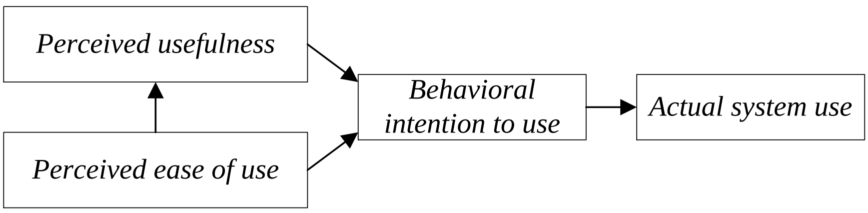

Figure 1. Technology acceptance model [9, 15, 16]

TAM has proven its value for explaining how users come to accept and use new technology, making it a good fit for our study. TAM posits that perceived usefulness and perceived ease of use will determine an individual's intention to use. TAM places a strong emphasis on the users and places the construct 'behavioral intention to use' as a mediator of actual system use. The main TAM constructs are: (1) Perceived usefulness – "the degree to which a person believes that using a particular system would enhance his or her job performance" [p.320, 12]; (2) Perceived ease of use - "the degree to which a person believes that using a particular system would be free of effort" [p.320, 12]; (3) Behavioral intention to use - users intention of use of the system in the future [17]; (4) Actual system use - users 'real' use of the system for performing work tasks [17].

3. Method

A case study was considered appropriate since it allows for exploring "sticky practice based problems where the experience of the actors are important and the context of the action is critical" [p.370, 18]. We decided to conduct our case study in a

Norwegian mixed use (apartment/office) construction project. The project included two buildings and a joint parking area beneath the buildings. The project is located near the center of Oslo. Our data was collected through semi-structured interviews with seven construction professionals working on site. Using interviews as the means of data collection served as a way to access the interpretations of informants in the field [19]. The interviews were conducted in February 2015, at a point in time when the design and construction had not been finalized. Table 2 provides an overview of the interviews conducted. Three interviews took place at the designers` offices and five in or near the contractor`s field office. Interview guides were designed based on the Technology Acceptance Model. The Gantt diagram was prepared using Microsoft Project ®, the flowline diagram by exporting the data from Microsoft Project® into Vico® Schedule Planer, and finally the 4D BIM model was prepared based on Vico® Schedule Planner and Synchro®. Eventually the Gantt-diagram, the flowline diagram and the 4D BIM model were presented for the individual interviewees on-screen. Informed consent was sought in advance of all conducted interviews. All interviews were voice recorded, transcribed, and coded by using the qualitative data analysis software NVivo10. Categories were derived from the data assigning nodes to notions, which could be related to the core concepts of the Technology Acceptance Model.

Table 2. Interviews conducted.

Affiliation	Service provided	Interview technique and duration
Contractor # 1	Superintendent (construction)	Face-to face, 25 min
Contractor # 2	Superintendent (construction)	Face-to face, 35 min
Contractor # 3	Project manager	Face-to face, 25 min
Contractor # 4	Assistant Project manager	Face-to face, 35 min
Contractor # 5	Superintendent (construction)	Face-to face, 20 min
Contractor # 6	Health and safety engineer	Face-to face, 35 min
Contractor # 7	Carpenter	Face-to face, 20 min

4. Analysis

The analysis follows the structure suggested by the Technology Acceptance Model presented in chapter 2. First, the contractors` perceived usefulness of Gantt, flowline and 4D BIM scheduling for carrying out their work is presented. Second, the perceived ease of use of the schedules in the context of on-site construction work is. Third, the behavioral intention to continue using Gantt, flowline and 4D BIM for construction works as an indicator for actual system use in other projects is depicted.

4.1. *Perceived usefulness*

Throughout the interviews, several factors were found influential for construction professionals' perceptions of usefulness. For instance, Gantt has proven its value in many projects over the years and has become the industry standard instrument for scheduling. Thus, it is maybe not surprising that contractor #1 found: "This is all very 'cool'…I mean this new visualization systems [4D]… but I am a bit old-fashioned and maybe narrow minded; the schedules that we use today [Gantt] work very well for me." (contractor #1). Thus, some perceived the relative advantage of using the new four-dimensional technology over the existing Gantt solution as marginal. Schedule visualizations prepared in Gantt were perceived as easy to understand when compared to Flowline and four-dimensional BIM: "Gantt is so much easier to look at" (contractor #3). Apart from being easy to understand the interviewees stressed that Gantt charts allowed for depicting the critical path of project activities which none of the others did: "…you have the critical path which is really useful to have for figuring out which activities need careful attention for the project to turn out well." (contractor #1). In essence, all interviewees viewed Gantt as a superior tool for assessing, discussing, and understanding the status of a project. Contractor #1 summarized this in the following way: "To work properly [in a construction project] I think that Gantt is and continues to be a brilliant instrument" (contractor #1). This opinion was echoed by contractor #5's statement: "Yes, this [Gantt] is what we are used to doing and it works very well for us."

The flow line chart was widely perceived as being a useful instrument for planning, too. However, all interviewees stated that given the choice, they would rather go for using a Gantt schedule. A reoccurring theme was that Flowline charts would need an alternative way of thinking and thereby would lack the intuitive understanding provided by Gantt charts. However, some stated that, once properly understood, Flowline charts could help providing practitioners with a solid understanding of possible scheduling conflicts: "When you are used to it (flowline) I believe it could be easier to see the collisions", (contractor # 3). One of the interviewees pointed out that Flowline could work well as a complementary visualization method used in combination with Gantt: "It is maybe a good idea to prepare the main schedule in Gantt and then use Flowline to explain some of the more detailed assemblies." Moreover, some interviewees perceived flowline as particularly useful when different work activities would need to be run concurrently.

Four-dimensional BIM was perceived as a good complementary instrument for scheduling and as a "…cool visualization technology" (contractor #1). It was mentioned how 4D BIM would provide a more complete and consistent overview when compared to a paper schedule: "A picture says more than a thousand words for us out here [on the construction site]" (contractor # 6) and "[…] one gets an overview of how it could look when it is finished" (contractor # 7). Four-dimensional BIM allows for an easy understanding of the project and its assembly which is why it was viewed as a good instrument for training new construction site personnel "In our last project we had introductory courses for new people and then this is great to have" (contractor #3). However, apart from being found useful for introductory courses the interviewees were critical towards four-dimensional BIM's value for day-to-day construction management. This observation is backed by the following two statements: "It does not really provide value for us [in construction management]" (contactor #5) and "I don't see how this can be really helpful throughout the construction process" (contractor #3). Nonetheless, it was considered useful for "getting the overall process in ones' head" (contractor #1).

4.2. *Perceived ease of use*

While Gantt was widely viewed as the scheduling visualization easiest to use, several concerns were voiced. Gantt charts were considered most easy to use when depicting few activities in conjunction with an easy readability of activity names. However, there is a tendency for these charts to become large, displaying several thousand activities and rendering Gantt less easy to use: "What did we have in our last project? Two thousand activities […] it was impossible to even print that schedule." (contractor #1). However, practitioners have developed ways to cope with large schedules by subdividing them in several smaller sub-schedules: "I am not any good at using MS Project, but I manage to make little plans. I just draw up parts of it by hand, I leave out most of the lines and then I have something to work with." (contractor #2). Reflecting on why the interviewees found Gantt easiest to use contractor #1 stated: "it is so that people find that which they always use safe and easy".

"In any case, I was not used to this [Flowline] from before" (contractor #1) was one practitioner's response when asked about his view on Flowline's ease of use. Moreover, he continued to state "I think it is very difficult to get an overview from this, at least at first glance. My first impression was that I found this to be very chaotic". Contractor #2 elaborated that "The thinking is very different, this makes it hard to understand for construction site personnel, this has to do with habit." However, when receiving a brief introduction by the interviewer one of the interviewees stated that "Ok, now I see, it is in fact well structured, maybe this is usable" (contractor #5). "This could make it easier to recognize scheduling collisions" stated another (contactor #2). However, contractor #2 doubted the practical applicability of this type of schedule visualization: "My opinion is that we are not ready to take this [Flowline] into use in our projects".

Despite wide interest and acknowledgment of its visualization capabilities by all interviewees, four-dimensional BIM was widely viewed as being difficult to use for supporting on-site construction operations. This follows from the following statements: "Having such a model requires proper design early on in the project […] moreover, schedulers would need the required IT capabilities before being able to use this on the job." (contractor #1). A limitation of four-dimensional BIM for operational day-to-day use was that only a few IT-literate people would be able to create and edit schedules. Moreover, the practitioners viewed a non-paper based solution as limiting their ability for interacting with schedules in their day-to-day work. The contractors found four-dimensional BIM too static and work intensive for supporting operational construction work.

4.3. *Behavioral intention to use*

The behavioral intention of the interviewees of using the different forms of schedule visualizations in their next construction projects is presented here. All of the interviewees stated how Gantt is likely to remain their preferred instrument for construction management. The interviewees were more skeptical about using Flowline charts in their next project, while some pondered using it complementary to a Gantt chart. While many viewed 4D BIM a promising tool for communicating the overall project schedule logic, the contractors viewed such a system as difficult to implement: "It would be great to have this. This is something we should have used in all projects. Everyone working in the project can see what is happening. It can be difficult enough for us that are managing the building process to understand what we are going to build before building it. With such a visualization, it is much easier to see it clearly. But such a model would require lots of scheduling in an early stage" (contractor # 1). The contractors found 4D BIM useful for early project stages, however they did not anticipate it as easy to use: "I believe in 4D BIM, but it must be quite hard to learn how to use and especially to explain it to others" (contractor # 2).

5. Discussion

Technology Acceptance Model served well as an analytical tool for explaining user choice of technology in the context of construction projects. An overview of the main findings related to the concepts of perceived usefulness and ease of use can be found in table 3. The findings indicate that visualization forms were viewed as useful for different aspects of the building process.

Table 3. Perceived usefulness, perceived ease of use and behavioral intention.

	Perceived Usefulness	*Perceived ease of use*	*Behavioral intention to use*
Gantt	➢ Organization of activities along a critical path	➢ Messy when many activities	➢ 'All-round' management tool
Flowline	➢ Organization of concurrent activities	➢ Difficult to understand	➢ 'Complementary' scheduling instrument
4D BIM	➢ Instruction of new site personnel	➢ Requires strong IT capabilities	➢ 'Complementary' scheduling instrument

Gantt was viewed as the 'all-round' tool facilitating day-to-day operations throughout the entire construction supply chain. This finding does not come as a surprise since Gantt is well institutionalized among construction professionals worldwide. An unexpected finding is that Flowline charts were viewed to be somewhat 'exotic' and that the interviewed Norwegian construction professionals struggled with understanding this form of visualization. This explains why the application area of Flowline schedules remains limited. Today they serve as complementary scheduling instruments in projects with many concurrent activities. The explanatory power and clarity of four-dimensional BIM was acknowledged by all interviewees. However, 4D BIM was considered difficult to use in day-to-day construction operations and management. Construction professionals felt constrained by having to use computers for viewing and interacting the content displayed in 4D BIM. Thus, people wanting to engage with the digital content would need solid enough IT/BIM capabilities. Research indicates that it is not until teams develop such capabilities that project performance improves significantly [20]. For now, 4D use is prioritized only in early project stages to, for instance, train new site personnel not yet familiar with the construction site. Thus, despite a wide availability BIM models in Norwegian construction projects, 4D BIM's utility remains low. Moreover, this is unlikely to change quickly since learning to operate four-dimensional BIM was perceived as difficult. Thus, four-dimensional BIM continues to lack technology acceptance even in advanced BIM projects. For now, practitioners view 4D BIM and Flowline as 'nice to have' complementary scheduling tools. Nonetheless, our findings would need to be validated beyond the case presented here. Thus, we recommend further research analyzing 4D BIM's acceptance in other projects and in different national contexts.

6. Conclusion

This paper has presented a case study of a construction project where Gantt, Flowline and 4D BIM were used. By comparing professionals' acceptance of the different scheduling methods for facilitating their day-to-day work based on TAM, it became possible to answer the research question: *How useful and easy to use are different schedule visualization methods for construction site teams?* Our findings illustrate that Gantt remains the most important scheduling tool for arranging the day-to-day activities in projects. Flowline was viewed as a useful system when scheduling many concurrent activities. However, some of the practitioners found Flowline to be difficult to understand. While four-dimensional BIM was acknowledged as a powerful visualization tool, it was at the same time perceived as difficult to use. The fact that practitioners' interaction with this digital scheduling method requires sophisticated IT skills represents a hurdle for its practical application. This is unlikely to change unless practitioners succeed in increasing their IT capabilities. Thus, even in advanced construction projects where BIM models are widely available, 4D BIM is viewed as little more than a complementary scheduling instrument. Future research should inquire into how the utility of 4D BIM can increased.

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BIM and Lean Construction Change Design Management Practices

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Abstract

Arguably, Design Management can be improved by utilizing new tools and methods introduced by Building Information Modeling (BIM) and Lean Construction. However, in the projects that use BIM, roles of personnel, design methods and the practice of communication between designers often derive from the era of document based Design Management and can only be partially adapted to a new way of working. In managing building design, the use of Lean Management tools can be seen a driver increasing value to the customer, improving operations and removing activities that do not add value.
In this context, the article discusses a study into the problems and improvement methods of structural and building services design management. The objectives were to identify typical design management problems that occurred on the operational level of BIM projects; to remove and decrease the frequency of identified problems by suggesting improvement methods and tools based on lean construction theory. Designers and design managers were interviewed in three case projects. The interviews were analyzed dividing problems in six categories, and the seriousness of problems was decoded. Recommendations for improvements were given to design teams.
In the end, 13 major and 6 average serious level problems were identified in the research. The most important causes for the problems were, an unclear sharing of responsibilities between designers in teams, inadequate BIM instructions, and insufficient BIM experience and knowledge of the design manager. The lack of communication between design team was seen as an important factor for the problems. By creating project environment that supports collaboration and communication, a design project can be improved. Lean tools, especially big room, knotworking, last planner and set based design can significantly facilitate collaboration.

Keywords: building information modeling; collaboration; design management; design team; lean construction.

1. Introduction

Projects that have several parties involved are typical for construction industry. There is a big challenge in the industry of how to make employees from different companies to work towards a mutual goal. The contract types used and the mutual relationship of participants make it possible for individual project parties to practice opportunistic behavior. In construction projects, there are several design disciplines involved that have to work effectively together in order to fulfill customers' expectations and requirements, and to avoid errors and conflicts in design. These challenges together with unsystematic design management and different design practices make it prone to design errors and conflicts to occur.

The researchers hypothesized that the design of a construction project can be significantly improved by implementing lean construction management practices and by intensifying the use of BIM. However, improvement requires that current problems that affect design process are first identified and resolved.

This research focused on design management practices between structural and building services design on an operational level of projects. The first objective of the research was to acquire a thorough understanding about the current design management practices and major challenges and issues in design projects. The second objective was to define suitable and easy to use lean construction methods and tools for the improvement of design management practices on an operational level of projects.

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2. Research methodology

The research consists of a literature review and an empirical investigation. In the literature review, previous studies and their results are examined along with the professional journals and text books of the construction industry.

Empirical data was collected from semi-structured interviewees that focused on three separate construction projects. The research followed the frame of the focused interview [1]. The interviews for cases 1 and 2 were performed in 2012-2013 and for the case 3 in 2014-2015. The basic information on cases is presented in Table 1. The questions posed were mainly the same in all three cases, including questions for BIM management and communication practices, design and modeling practices used, important schedule related issues, challenges and problems that have affected the case projects. In case 3, additional questions of lean philosophy and design management were included. All the interviews were recorded, transcribed, categorized and analyzed.

Problems identified were divided into six different categories. For each problem frequency, seriousness and potential tools that could be used to remove these problems were defined. The identified problems are presented in Table 2.

3. Literature review

Use of BIM and lean design management can lead to an increased value realization for the customer. The content of design work can be visualized and design tasks that do not create value can be identified and removed. At the same time, value adding tasks can be improved. Also the number of design cycles and design errors can be decreased which further leads to a faster, smoother and more economical construction process. [1]

BIM greatly reduces design conflicts by relying on one information source and enabling clash checking. It has enabled a better visualization of form and evaluation of function. Other improvements include easier generation of design alternatives, better maintenance of information and design model integrity including reliance on a single source of information and active clash detection. Design requirements are also easier to define and information flows are improved. As a result of reduced cycle time of drawing production, the conceptual design phase can be extended. [3]. BIM has succeeded in changing work processes and removing much of this waste. Sacks et al. [4] have studied the synergies of BIM and lean. In this research, 24 lean principles and 18 BIM functionalities were used and 56 interactions were found between them. From these interactions, 52 were positive. [3].

Lean in its simplest form means eliminating waste from every stage of a work process and at the same time producing added value to the customer by completing value adding functions as effectively and quickly as possible. [5], [6]. The use of last planner system has spread from construction management to design management. The purpose is to maximize the productivity of labor, resources and materials and in addition, improve the managing of issues related to construction project variability and work-flow smoothness. Using last planner system in design and design management can lead to improvement in project transparency through schedules, design structure matrices and percent plan complete [7].

Lean principles are used to generate value for the customer. The essential idea in target value design is to make clients value a driver of design. These can be specific design criteria, cost, schedule or constructability. Choosing this driver of design can lead to the reduction of waste and fulfilling or exceeding of client's expectations. [8]. There is evidence that projects are often completed as much as 19 percent below market costs when using target value design. The value is produced in the cooperation between project parties. [5].

Collaboration between parties could be facilitated using ideas of big room and knotworking. The basic idea of big room is that different designers work side by side in the same location. This enables more effective information sharing between them when compared with working different locations. Big room decreases the latency of decision making. Information can be asked face to face instead of using remote communication tools or waiting for proper meetings. This leads to a shortening of overall design time by decreasing the duration of single design tasks. Big room is best suited for large construction projects where designers can work only on one project at the time. However, construction projects are not typically this large in Finland. For this reason the altered form of big room, which is called knotworking has been created. The basic idea of knotworking is that designers meet at the same location in the planned or spontaneous critical points of the project when cooperation benefits the most. These knotworking points usually last for a few days after, which designers can go back to their own offices and continue to work on their respective projects. [9].

4. Results and analysis

Problem analysis is based on interviews made in three construction projects (Table 1.). Each of these projects was located in Finland.

Table 1. The basic information of projects used in the research.

Project	Case 1	Case 2	Case 3
Number of interviews (structural/building service)	5 (3/2)	6 (4/2)	6 (3/3)
Construction type	New building	New building	New and renovation buildings
Type of project	Turnkey contract	Speculative builder	Management contract
Location	Metropolitan area	Central part of Finland	Metropolitan area
BIM instructions	Project specific	Project specific	COBIM 2012
BIM coordinator	Client hired BIM consult	Structural designer	Client hired BIM consult

4.1. *Project management and competence related problems*

Project managers were not familiar with BIM. When project manager is not familiar with BIM, it is challenging for him/her to correctly evaluate the scope of design and modeling contract and the magnitude or time requirements of modeling processes. The actual modeling skills of project manager are not mandatory even though these would be recommendable. BIM related process instructions have been made that describe project manager's required BIM competence and main responsibilities. Project manager has to be aware of these and they should be prerequisites in working as a project manager in BIM project. If project manager is not familiar with BIM the design discipline-based person in charge of modeling should assist project manager throughout the project. This person participates in meetings where modeling is involved and works closely with project manager. He/she also assists project manager at the beginning of the project when the modeling contract and modeling practices are defined.

Essential aspect in preventing conflicts between different models is that there is a BIM coordinator in the project and design discipline based persons in charge of modeling are defined. The BIM coordinator inspects combination models and creates clash reports, which are presented in modeling meetings. These meetings have to be organized as often as required. However, BIM coordinator and modeling meetings do not eliminate the importance of communication and effective design collaboration between design managers.

Issues with tight design schedules were a common problem and general opinion among interviewees was that it is occurring in most of the projects. However, the severity of it depends largely on the project type and is project specific. Project managers have to comment on the content of the schedule if they think it is impossible to be realized. For this reason, project managers have to be familiar with BIM if it is used in the project. Otherwise, it is challenging to identify schedule related problems early enough.

Table 2. Identified problems in case projects.

Identified problems	Type of problem						Cases	Seriousness	Lean tools suggested as solution				
	Technology	Communication	Instruction	Project management	Competence	General			Big Room	Knotworking	Target Value Design	Last Planner	Some other
Acquiring required input data on time from other design disciplines was problematic.		x					1, 2, 3	Major	x	x	x	x	x
Collaboration between designers did not work. Problems have rather been solved alone than in cooperation.		x					2	Major	x	x	x	x	
Changes in input data caused redesign in building services design.		x				x	1, 2, 3	Major	x	x			
Modeling instructions were not used in the project.			x				1, 2	Major					x
Proper instructions for void provision phase were not sent or they were not sent on time.			x				1, 2, 3	Major	x	x			
Void provision instructions were not properly examined in the building service design.			x				1	Major					x
Project manager was not familiar with BIM.				x	x		1, 2, 3	Major	x				
Design schedule was too tight and there was little opportunity for designers to affect its creation.				x			1, 2, 3	Major	x	x	x	x	
The modeling scope defined in the contract did not correspond to the reality or designers were not aware of the modeling scope.				x			1, 2	Major	x	x		x	
The BIM coordinator was not defined in a contract.				x		x	2	Major					x
Conflicts between models from different design disciplines.				x			1, 2, 3	Major	x				
There was no practice of collecting internal project feedback.						x	1, 2, 3	Major					x
Response time between design disciplines was too long.		x					1, 2, 3	Average	x	x	x	x	
An architect model changed and caused redesign.		x					2, 3	Average	x	x	x		x
A sufficient number of section drawings were not delivered to the building service designer.		x					2	Average	x	x			
The client was not familiar with BIM.						x	1, 2	Average					x
Client requirements changed and caused redesign.						x	2	Average	x	x	x		x
Model revision documentation has not been done and changes had to be found visually.	x					x	2	Average					x

4.2. *Communication related problems*

Acquiring required input data on time is an essential prerequisite for an uninterrupted design process. If the required data is missing, the design process is disturbed. This was one of the most essential problems that affected the design process. It partially results from the fact that design disciplines do not understand each other's processes and requirements and thus cannot recognize, if input data required from them is critical for the design process to continue. The problem was also linked to the observation that it takes too long time to receive an answer to an email. Before the answer is received, the design process cannot proceed. The introduction of BIM has not removed the importance of section drawings as building services designs input data. However, it was viewed that as a result of BIM, the number of published section drawings had decreased and currently not enough of them are received.

Collaboration between designers has not worked. This resulted from the fact, that designers were not familiar with each other. Organizing a design group that works effectively together is a challenging task for the design management. Design disciplines worked in separate offices. Therefore, no face-to-face communication was practiced in daily work. Collaboration between parties is needed, especially in coordinating change management situations. Interviews indicated that the architect model is not always updated according to a structural model. This leads to problems because building services design uses the architect model as an input data and geometry of structures is critical for their design. A BIM coordinator and design managers together with a design discipline based person in charge of modeling have to take care of this issue.

4.3. *Instruction related problems*

In the projects studied, proper modeling instructions were not used. These instructions should be created by the client or the owner of the project in cooperation with design disciplines at the beginning of the project before the modeling process has been initiated and they have to be presented in the project initiating meeting. First, instructions should define how modeling should be done. This includes the software versions, file formats, how often the model is shared, location of origin and other issues related to the actual creation of the model. Second, instructions should define what is to be included in the models. In the projects, only the necessary modeling objects were highlighted in the instructions. Third, special process related instructions should be published and followed carefully. These instructions include, e.g., void provision instructions and a list of critical structures.

It is most likely that the use of comprehensive instructions would improve the cooperation and design process. Importance of active project management and design supervision is essential part of successful void provision and this also includes the utilization of instructions. A design manager together with a designer responsible for the void provision phase have to make sure that each designer is aware of the importance of using prearranged work methods, which include the use of instructions. Also structural designers have to publish instructions well in advance so that building services designers can take advantage of them.

4.4. *General unsorted and technology related problems*

Collecting of project feedback should be an essential part of project closing procedures. For each design disciplines there were guidelines stipulating that this must be done. However, it was not practiced in any of the cases analyzed. The reason for this might be that project managers are not aware of the real importance of feedback as a learning tool or they have an attitude problem towards collecting feedback. The feedback is an essential source of knowledge when working methods are changing. Each designer learns and discovers new working methods and evaluates them during the project. If the feedback is not collected, then the sharing of this information is limited. As a result, these same observations are done several times in different projects and the same mistakes are made repeatedly. A large scale sharing of knowledge would require a systematic feedback system.

A project manager’s responsibilities should include the reporting of the internal project feedback. This would consist of the evaluating of the work methods used in the project. Modeling tools and design practices that work and those, which need more development would be reported. Also the methods of collaboration between other design disciplines would be included in this report.

4.5. *Recommendation for the use of lean tools*

It is proved that the utilization of last planner system increases project efficiency and transparency, and enhances the project collaboration and commitment. It also improves team work. [7], [10] The preparation of the phase pull schedule in the last planner system helps participants to understand each other’s processes and requirements. Another potential tool is target value design. It has an overall positive effect on the collaboration of participants. More attention is given to the earlier stages of a project and meetings are held at least on a weekly basis. In target value design, cooperation between participants is much greater than in a typical construction project. However, the utilization of a target value design has to be a client oriented process because the contract and project risk management are the basis of target value design.

Big room improves information sharing and decreases communication latency because it can be practiced face to face. A brief weekly video conference between design managers would improve design cooperation. Video conferences are suggested instead of traditional meetings because time requirements are not as great due to the lack of travel. Big room and knotworking would lower the threshold to practice collaboration because designers would become familiar with each other and conversation would not require the use of phone or email. More importantly, it would enable a work method where the whole design process is done in full collaboration. Benefit of this is greater in big room but it can still be acquired using knotworking even though only certain moments of the design process would be done in full collaboration.

5. Conclusions and summary

In the analysis of the empirical data it was discovered that certain problems typically occurred together. Especially the absence of a BIM coordinator, not defining designers responsible for the modeling, not creating sufficient instructions, and the non-collaboration culture between design disciplines could be affiliated to the occurrence of several problems. Even though both structural and building service design teams were used to BIM, the full potential of modeling could not be reached. Lean tools presented in the literature review were found to be potential in the removal of problems. However, a full scale utilization of these tools would require that the lean culture has been adopted in the strategy of the company.

Big room was found to be the most widely applicable tool for major problems. It was identified as a potential solution for 12 different problems. The second most widely recognized tool was knotworking, which was identified as a solution for ten problems. Target value design was identified as a solution for six problems, and three of these were rated being of major seriousness. Last planner system was identified as a solution for five problems and four of these were problems of major seriousness.

Remarkably, it was discovered that the removal of several major problems does not necessarily require the use of special tools. Instead, being aware of these problems, using comprehensive instructions and having competent project manager and designers in the team can have a significant effect on the occurrence of these problems.

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The Integration of BIM in Later Project Life Cycle Phases in Unprepared Environment

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Abstract

The article examines the topic of Building Information Modeling (BIM) from the perspective of the owner in an environment that was not prepared correctly for later BIM integration. The best way to utilize BIM is to use this tool from the beginning of a project, according to the concept of Integrated Project Delivery (IPD). But there are many projects, which started without the opportunity to implement BIM in the beginning. The question is, whether it is possible to utilize BIM in later project life cycle phases, especially during its operational phase, even when there is no proper BIM environment from preceding phases (i.e. no model, no BEP, no common environment etc.) The paper answers this question by explaining possible benefits of BIM in later project life cycle phases. Such benefits are especially: easier data transfer from BIM model to CAFM system, possible way to maintain live as-built documentation for future use from the beginning of any building related project and possible way of future utilization (i.e. prolongation of the moral age). The paper also presents three simple case studies of various projects in later project life cycle phases (*Building A* of *CTU in Prague, Faculty of Civil Engineering*; *Czech Institute of Informatics, Robotics and Cybernetics* of *CTU in Prague*; *SHQ* of *ČSOB*). The BIM model was utilized in these projects for various reasons. In the end of the article, lessons, which were learned during the process are presented and they are generalized for future use. The most important findings were 1) facility management (FM) cooperation is mandatory for the project purpose, 2) it is very important to specify requirements for deliverables, 3) there is a great value in the experience from BIM utilization even in later project life cycle phases, and 4) when BIM is used as a tool, it might be successfully utilized even later on in the project and existence of the model might have other future advantages for the project.

Keywords: BIM; Building Information Modeling; facility management; project life cycle; operational phase

1. Introduction

Building Information Modeling (BIM) is a worldwide topic in construction industry nowadays. As industry became more and more familiar with BIM methodology, there are new challenges and opportunities. One of such opportunities is the utilization of BIM models in facility management (FM). And this paper strives to prove that BIM is a useful tool even when used only in facility management, the last phase of project life cycle. The reasoning behind this decision is simple. From the life cycle costs (LCC) perspective, the operational phase of construction projects is often considered the most important, because life span of projects in construction industry is considerably long. During the operational phase, most costs are associated with energy consumptions, operation, maintenance, repairs and reconstruction or demolition. With the arrival of BIM, industry was given an opportunity to utilize information models during operational phase to increase its quality and efficiency, i.e. the possibility to reduce costs.

This paper will not compare these non-standard situations with typical utilization of BIM. Typical process of BIM utilization in operational phase considers creation of a model from the beginning of the project. As the project programming and design starts, the model is created and can be used throughout whole preparation and realization

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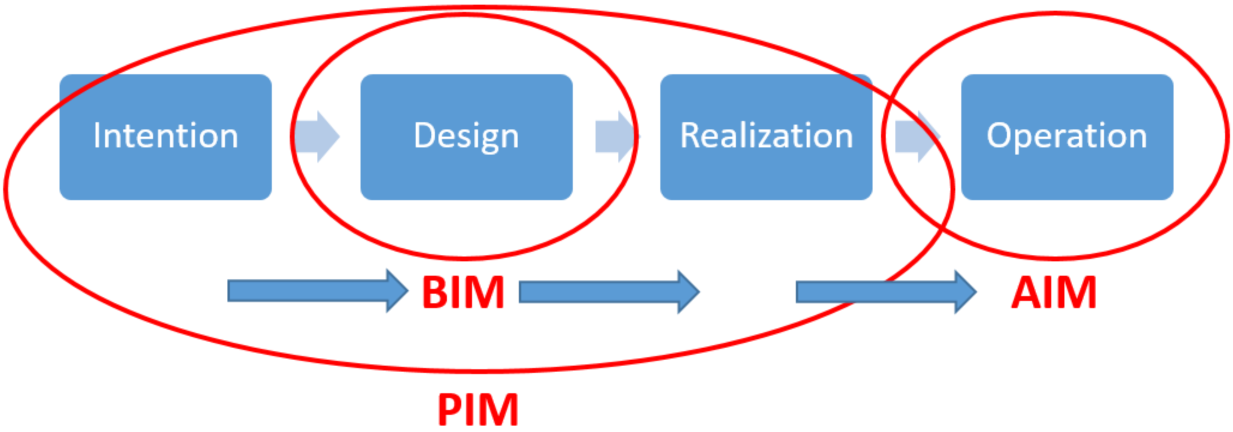
phases. The way this is done may vary greatly based on many different project conditions and requirements. This paper does not describe these phases. Rather, it shows a model, which can be, more or less successfully, turned over to operational phase. A model which may be applied in the end of realization process (and sometimes even sooner) regardless of methods, processes or platforms. As shown in the figure 1, the building information model (BIM), which is mainly created during design process, is part of the project information model (PIM), which provides information for the asset information model (AIM) used in operational phase of the project.

Figure 1: BIM, AIM and PIM relationship (source: author)



This is the case of so called *BIG BIM* [1]. However, there are many construction projects, which were planned, designed and realized without any use of BIM. Mostly because they were started before BIM was a part of common practice, but there are also current projects which do not fully utilize BIM for various reasons. This paper aims at answering some common questions of construction industry: Is BIM still worth being applied even at the end of realization phase? And how should it be done properly? The authors were repeatedly faced with such questions. This paper is an outcome of practical case studies where the decision had to be made whether to use BIM or not. It discusses needs of projects, advantages of BIM but also problems which need to be judged before making a decision.

2. Literature review

Topic of FM and BIM is widely discussed in scientific journals. Articles usually refer to the topic from a perspective of facility manager or owner, who is the end user of information model. Such is a case of [2], for example. This article describes a framework of evaluation and presents possible ways to assess and expand technical knowledge of owners and facility managers by assessing their BIM competency. On the other hand, [3] discusses the handover issue from the data format perspective. There are also articles dealing with the topic of BIM utilization in FM in more general way, like [4], [5] or [6]. These papers present key benefits of BIM integration in facility management or points out problems connected with this topic. There are also some supporting case-study articles, like [7], [8] or [9], but more thorough case studies are usually presented in scientifically oriented books. Other relevant topic is the problem of BIM adoption into facility management (i.e. BIM transformation into AIM). Such topic is, for example, dealt with in [10] or [11], where needs of FM are identified, clarified and accepted, based on both experience and survey. In 2012, an article presenting study of Pennsylvania State University initiative to utilize BIM for FM application [12] was published. It focuses on operational requirements and their specifications from experience. Such specifications are extremely valuable for future development projects, but they are also highly dependent on project specifics and requirements.

Interesting article [13] points out, that the topic of BIM from FM perspective should not be restricted only for new construction, but also for existing buildings. Comprehensive literature review has been done in the research for this paper. Based on this research, three main challenges were identified. These challenges are [13]:

- "*High modeling/conversion effort from captured building data into semantic BIM objects*
- *Updating of information in BIM*
- *Handling of uncertain data objects and relations in BIM occurring in existing buildings*"

The topic of BIM and FM is very common in scientific publications. The operational phase is often mentioned in general BIM literature like [14] or [15], where BIM is described as opportunity, especially because it is an excellent tool for implementing integrated project delivery (IPD) approach. Other publications were written with special regard to facility managers [16] or owners [17]. Such books examine the topic more thoroughly than general literature, using FM perspective as a central viewpoint. They address key BIM-FM issues and usually also present case studies of BIM utilization in various projects. Such projects are exclusively newly constructed projects or reconstructions. There are no case studies of projects where BIM was used for asset management without previous BIM utilization during design or realization phases.

Based on the literature review, it is possible to state that BIM has considerable advantages for FM, but the proper way of implementation (especially problems with specification of data requirements and problems with their actual use) and decision making process about BIM integration are contemporary issues. This makes sense, because the attempt to use BIM in such late phase should be considered as bad practice and failure of proper BIM utilization in a project. On the other hand, it does not reflect reality, since many such construction projects exist in the whole world and will surely continue to exist in near future. This topic is not covered in scientific literature at all.

3. Research case

The problem of BIM utilization for projects in later phases is a very complex topic. There is a big discussion in scientific literature about the value of information gathered throughout project life and how such information may be used. But there is a lack of knowledge about return value of such information (i.e. creating models) just for the purpose of facility management. It is very hard to calculate costs and benefits of these processes and when they are calculated (usually retrospectively), they are dependent on relevant projects. Attempts to use such cost calculations for different projects decrease accuracy even more.

When facility management system is implemented, it has to be supplied with necessary data. Part of such data (like design sheets, some geometrical data, revisions, manufacturer information etc.) may be included in a BIM model, but they can also be delivered without a BIM model. So the question might be why even bother with BIM for later project phases. There are three main advantages of BIM in later project phases:

- Data transfer from the model is much more efficient than manual data input; this is especially noticeable in bigger projects.
- BIM model may be maintained as current as-built documentation and used easily in future changes to construction; in an ideal scenario there may be live connection between model and computer aided facility management software (CAFM). Such model brings potential for future utilization of BIM in other similar projects.
- Modern technology is very fast in progress, which results in the fact that construction projects become obsolete much faster than in the past. The absence of a model further aggravates the problem. Mere existence of a model has therefore potential to prolong moral age of the project and might bring various synergies throughout its remaining part of life cycle.

Although mentioned advantages are clear, there is still the issue of return value and other questions. Problems of creating a model in later phases are widely discussed in [13]. Moreover, there is often the issue of contract terms and conditions (especially requirements specification), where deliverables have to be stated. This is not so much of an issue in new construction projects or general reconstructions (where there are major changes to operation of the building). According to the concept of integrated project delivery (IPD), the owner or facility management may easily specify all necessary requirements before the operation phase. Operation phase (and especially facility management system) is planned during design or realization phase of the project.

When BIM model is considered as an option, the typical approach is usually the *decision approach*. The decision whether there will be a model or not is made first. Then it is followed by realization. There is nothing wrong with this approach, as long as it is based on a qualified decision. Adequate resources are also necessary for finding proper solutions and realization of the intention. If the decision is based on both qualified judgement and adequate means, it is largely beneficial. Unfortunately, this is often not the case. On the other hand, the decision approach is straightforward and is often the only viable way of initiating BIM adoption process. There is also the *requirement approach*, which is based on the possible use of modern technologies. The use of such technologies often has specific requirements. Also, the use of such technologies results in specific deliverables, which might or might not be used (this is often an issue in traditional delivery systems, for example when project is designed as BIM model but supplier is not able to use BIM data). Decision approach may be utilized without preparation in advance, requirement approach cannot. If we want to specify requirements, we need to be familiar with expected outcome.

The paper examines described issues from the owner perspective. The case scenario considers larger construction project in later life cycle phase (late realization or operational phase) and how the decision making process concerning any kind of BIM implementation works in such projects.

4. Methodology

The research is based on literature review and practical experience of authors. This knowledge defines the system in which specific projects are examined. For the examination, three projects were chosen and comprehensive case studies were created. Structured questions were asked to key project personnel and answers were analyzed. Analyses were then used for deduction, which resulted in mapped decision-making process with commentaries. These decision maps were then synthesized into generalized schematics and best/worst practices, which are presented in the results section of this paper.

5. Results

This chapter of the article contains case studies of three projects. These projects are similar in their approach to BIM modeling and possible following use of models in project operational phases. Each project has a different motivation for BIM model creation with different results. In the last subchapter named Outcomes, lessons learned are summarized.

5.1. *Case studies*

For the purpose of the paper, only brief information is presented, because of the article extent restrictions. Also, many of the data cannot be published due to legal restrictions. The emphasis was put on such parts of case studies, which are the most relevant for the paper.

5.1.1. FCE A

The Czech Technical University in Prague (CTU), Faculty of Civil Engineering (FCE) decided to upgrade its facility management system in the future. This decision is connected with a big reconstruction of some faculty buildings which was planned. There is a possibility to use BIM during this reconstruction and model should then be used for FM after reconstruction. The problem of requirements specification was identified as a part of preparation phase, when the model of existing building (*building A*) was created. This model was meant to be created according to requirements of new facility management system. Unfortunately, due to time pressure, it was not possible to specify all requirements in the contract. The new facility management system is not operational yet and there are still some decisions waiting to be made. Regardless, this was an extremely important milestone for the FCE. If a model of *building A* was not to be created, the necessity to create requirements would arise during the reconstruction of other faculty buildings, and they would not be prepared properly. As a result of the contract, not only was the model created, but also requirements for the future models were defined, according to the specific needs of faculty FM. Model of *building A* was also used for demonstration of possible functionalities of new FM system. The investment into model creation was supported by the fact that model can also be used as an educational tool for BIM oriented classes at FCE.

5.1.2. CIIRC

There is an ongoing big reconstruction of former canteen and administrative building of CTU in Prague. The reconstruction will create new spaces for Czech Institute of Informatics, Robotics and Cybernetics (CIIRC) and other facilities. The information model was created during design process, but there was no level of detail (LOD) or level of information (LOI) specified. Therefore, the model is merely a 3D model of the building. There was not any logical structure of the model and it was not a part of project preparation or contracting. A model of the building brings a significant advantage as other information for FM can be added later into an already existing tool. CTU decided to implement FM that can utilize BIM as a part of its future strategy. Additional information will therefore be gathered in the end of realization process of CIIRC project on CTU expenses. It was necessary to specify required information on general level (i.e. not to stick to one selected CAFM tool) first, so that additional information in later phases is endorsed. Unfortunately, this was not possible in the beginning of the project, due to lack of expertise. Also, an old FM system was used, which does not support any BIM import. Furthermore, some decisions about specific FM tools for CTU were not made yet, so it was not clear how information exchange would continue and what information should have been included in the model. The communication between FM experts and project team was important to specify requirements for the model on general level, so there will be less additional work and changes to the model in the future.

5.1.3. SHQ

Compared to CTU projects, *Československá obchodní banka, a.s.* (ČSOB) is not bound by public contract legislation. As a part of preparation phase for the construction of the new headquarters building (South HQ – SHQ), it was necessary to specify requirements for the whole project (to prepare BEP, to define LOD and LOI, solve many security issues etc.) ČSOB made strategic decision to use modern CAFM system in the past, but BIM was not common practice in the Czech Republic by that time. To prepare for the construction of new headquarters, ČSOB identified possible savings when BIM is properly utilized. To be able to specify relevant requirements for SHQ, ČSOB decided to create BIM model of current headquarters (North HQ – NHQ). Existing documentation was partly transformed into BIM and then used for FM purposes and for education of FM staff. This way, FM department of ČSOB was able to actively participate in the SHQ project. This cooperation was mandatory for proper BIM utilization in ČSOB. The project of SHQ will be one of the biggest BIG BIM project in the Czech Republic.

5.2. *Outcomes*

From the experience and case studies of mentioned projects, following outcomes were formulated:

- Requirements for PIM and AIM have to be defined, according to the project goals. These requirements should be defined in the most specific way possible, but even if they are not, the whole process of their defining is an extremely valuable lesson for future projects.
- FM participation is mandatory. Even though IPD principles are best applicable from the beginning of the project, it is also possible to gain added value from later collaboration. End user participation is very important for proper specification of requirements, and risk management.
- Even a simplified BIM model for an already existing building may be used as a tool and knowledge base for the future BIM implementation into FM. The value of experience is extremely high for BIM related projects. It is very hard to successfully implement BIM without prior experience in similar environment, and every project in construction industry is different.
- The integration of BIM in later project life cycle phases is possible, but it is not necessary to stick to BIG BIM. BIM should be used as one of many tools, which may achieve desired goals but also has future potential.

6. Conclusion

The article examined the topic of BIM from the perspective of FM in projects, where BIM model was not created during design and realization. Opportunities of BIM utilization during operational phase of project life cycles are widely known, but that does not necessarily justify creation of a model in later project phases. Still, when such decision is made, it might be beneficial for the owner. But it is extremely important to model efficiently, i.e. follow requirements and not end up in doing BIM for its own sake. When requirements are to be followed, they must be specified beforehand. Although there are many predefined specification formats we can use or guidelines we can follow, these standards are usually country-specific or very general (like COBie for example). To fully utilize benefits of BIM, requirements have to be specified according to relevant project needs. To specify such project dependent requirements, facility management integration is necessary. Simply put – it is very hard to specify what we want, if we do not know what we will use it for. It is good practice to use any kind of general reconstruction or new construction as an opportunity to modernize FM system with or without BIM. For existing buildings, the main aim should always be defined by needs and possible information utilization. BIM model might not always be necessary, but could be useful in many ways and its creation should be considered. Return value should be calculated and decisions should be made with enough information, which might often be hard to get. Information regarding FM needs and future development is especially valuable, as well as information regarding BIM and its key aspects.

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