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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 of 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.

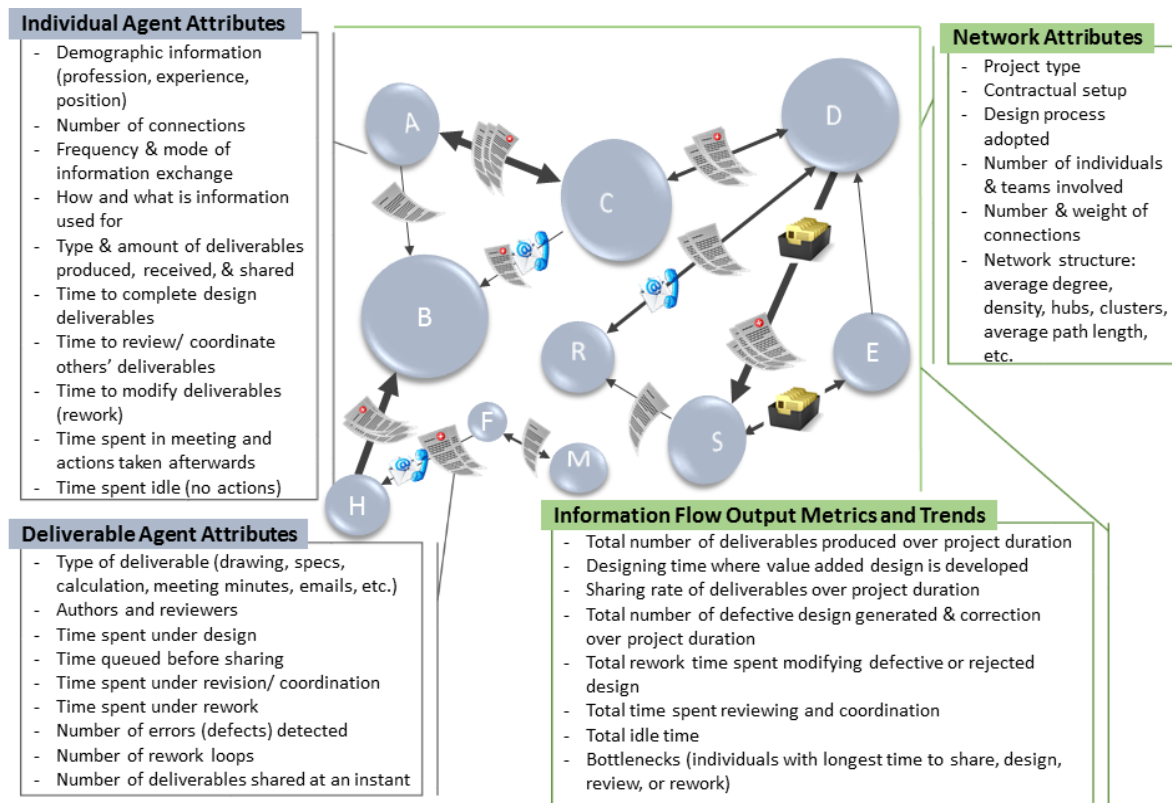


Figure 33. Social network topology of agents and metrics

Table 24. Social network metrics

Type	Metric	Definition (this metric describes)
Node	Degree	Measures the number of links an individual has with others
	centrality	
	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.

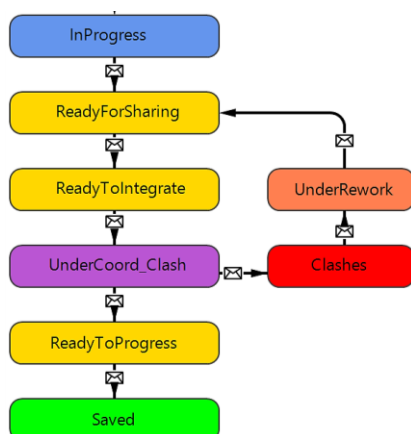


Figure 34. State chart of a BIM model agent project

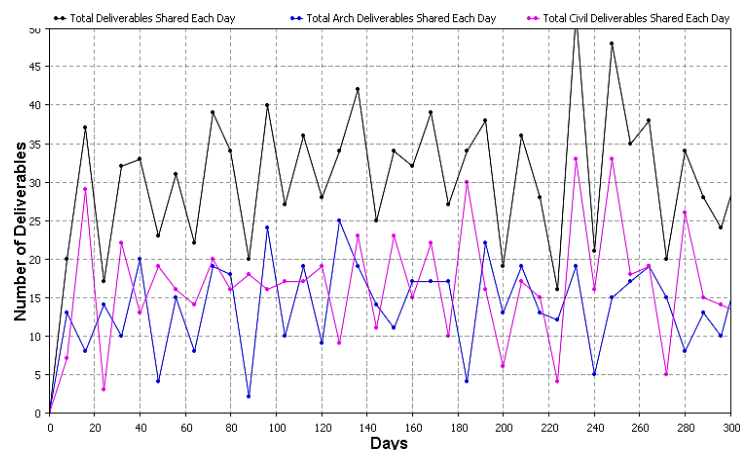


Figure 35. Information sharing trends on the overall project

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 patterns 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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References

- [1] M. Arashpour and M. Arashpour, "Analysis of Workflow Variability and Its Impacts on Productivity and Performance in Construction of Multistory Buildings," *Journal of Management in Engineering*, ASCE, 2015.
- [2] F. R. Hamzeh, E. Zankoul, and C. Rouhana, "How can 'Tasks Made Ready' during look-ahead planning impact reliable workflow and project duration?," *Construction Management and Economics*, Taylor and Francis, vol. 33, no. 4, pp.243-258, 2015.
- [3] G. Ballard and L. Koskela, "On the agenda of design management research," in *Proceedings of the annual conference of the International Group for Lean Construction (IGLC)*, Guarujá, Brazil, 1998.
- [4] G. Ballard, "Positive vs. negative iteration in design," in *Proceedings of the 8th International Group for Lean Construction Annual Conference*, Brighton, UK, 2000.
- [5] A. N. Baldwin, S. A. Austin, T. M. Hassan and A. Thorpe, "Modeling information flow during the conceptual and schematic stages of building design," *Construction Management and Economics*, vol. 17, no. 2, pp. 155-167, 1999.
- [6] E. Tribelsky and R. Sacks, "An empirical study of information flow in multidisciplinary civil engineering design teams using lean measures," *Architectural Engineering and Design Management*, pp. 85-101, 2011.
- [7] S. D. Pryke, "Analysing construction project coalitions: exploring the application of social network analysis," *Construction Management and Economics*, vol. 22, pp. 787-797, 2004.
- [8] P. Parraguez, S. D. Eppinger and A. M. Maier, "Information Flow Through Stages of Complex Engineering Design Projects: A Dynamic Network Analysis Approach," *IEEE Transactions on Engineering Management*, vol. 62, no. 4, pp. 604-617, 2015.
- [9] L. Lopez, J. F. Mendes and M. A. Sanjuan, "Hierarchical social networks and information flow," *Physica A*, vol. 316, pp. 695-708, 2002.
- [10] C. Durugbo, W. Hutabarat, A. Tiwari and J. R. Alcock, "Modelling collaboration using complex networks," *Information Sciences*, vol. 181, 2011.
- [11] C. M. Macal and M. J. North, "Agent-based Modeling and Simulation," in *Proceedings of the 2009 Winter Simulation Conference*, 2009.