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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

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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.

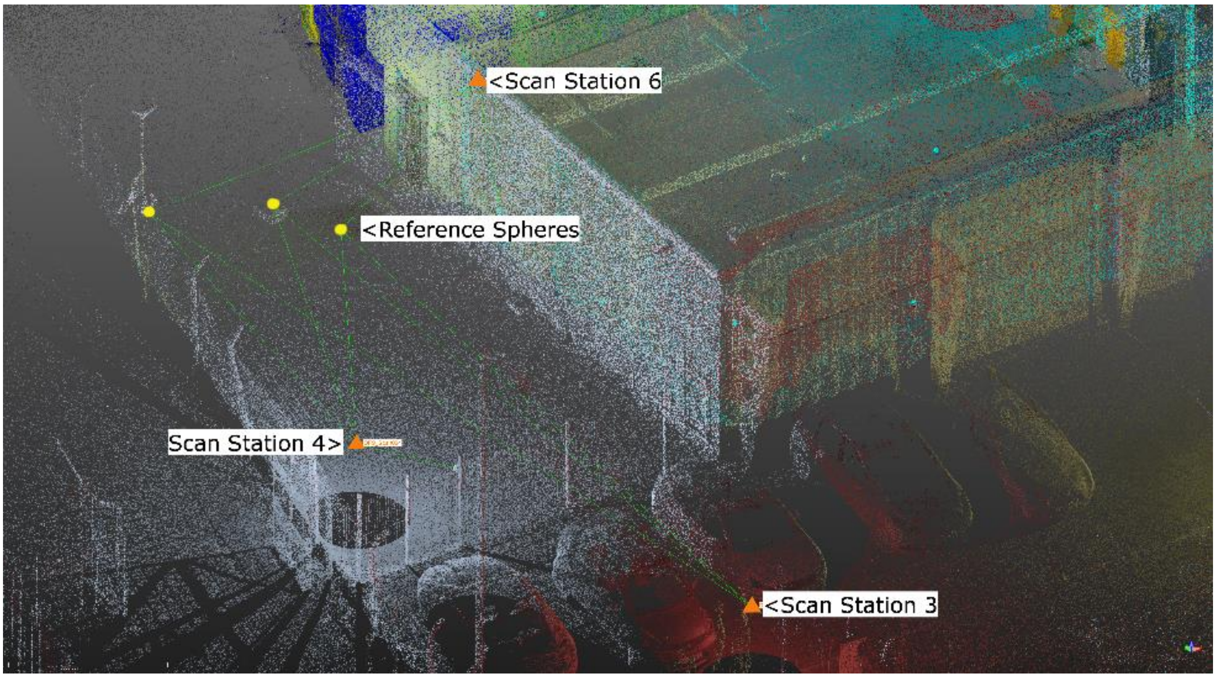
The image on the right (Figure 2), inside the side pedestrian door, is of the 3D point cloud which is initially captured in greyscale during the first rotation of the scanner. It is then coloured by Realworks during registration from a 360° panoramic camera image (shown on the left), captured during 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.

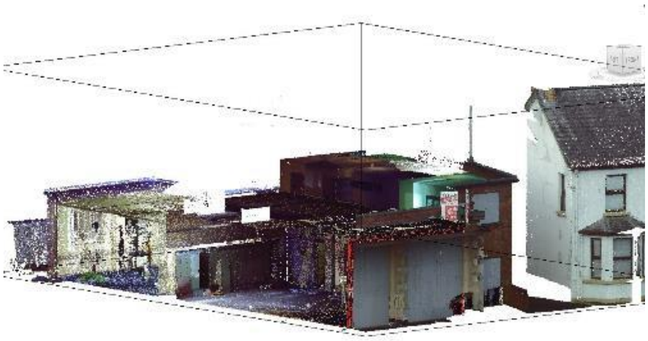


Figure 3. Cut-Away View of Point Cloud

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.

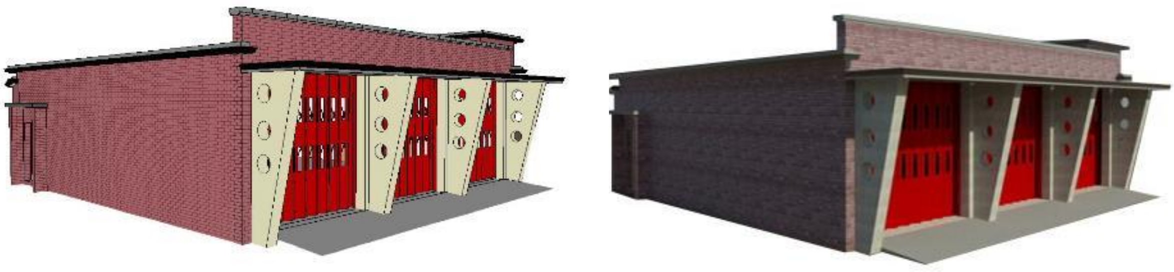


Figure 4. Work in Progress and Finished Rendered Revit Model

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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