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BIM for Existing Buildings: Potential Opportunities and Barriers

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Abstract. Building Information Modelling (BIM) can play a significant role for better operation and maintenance (O&M) and building facility management (FM) through the use of Information and Communication Technologies (ICT) tools. However, most of the existing buildings have no BIM. Research in creating BIM for existing buildings has received growing attention in recent years. It is evident from current literature that generating BIM for existing building is complex, tedious, time consuming and costly. The objective of this project is to explore potential opportunities and barriers in constructing BIM for existing buildings. Different techniques used in capturing building data such as imaging, 3D scanning, Ground Penetration Radar (GPR), 2D scanned plans and so on, have their pros and cons in terms of high modelling/conversion efforts necessary to construct a semantically rich BIM. Moreover, most of these techniques are complex; require expert knowledge; core steps are still manual; face challenges in handling occlusions/uncertain data; and BIM conversion becomes cumbersome with the BIM's increasing level of detail (LoD). A systematic analysis is done on various techniques used in data capturing and how they are converted into a semantically rich BIM, accuracy of the converted model, interoperability of the generated BIM in terms of functionality, potential barriers in the automation process and how they can be overcome.

1. Introduction

Building Information Modelling (BIM) is becoming the core of information management in Architecture, Engineering & Construction (AEC) industry as well as for operation and maintenance (O&M) and facility management (FM). It allows all stakeholders to exchange and manage information about building components throughout the lifecycle of a building [1]. Particularly, BIM can be used for energy usage analyses, defect detection, firefighting, renovation and demolition, safety in facility management and so on [2-5]. BIM adoption in AEC industry is well established and has received growing attention for O&M and FM [6-8]. Although, there is an increasing trend of BIM adoption in AECO (Architecture, Engineering, Construction and Operation) industries, it has only been used for some new projects in recent years [9]. Hence, most of the existing buildings do not have a BIM. In order to fully realize the benefit of BIM, it is necessary to create BIM for existing buildings.

Researchers have been working to create compatible BIM for existing buildings. Nevertheless, creation of a semantically rich BIM is challenging, complex and expensive considering the special equipment requirement for data capturing, high modeling/conversion effort, expert knowledge of skillful personnel, handling obstacle/uncertain data and so on [10-13]. Moreover, the complexity of BIM generation also depends on the BIM's level of detail (LoD), intended use, interoperability and functional issues [12, 14-16]. Hence, the potentials of BIM for existing building has yet to be fully realized.



This study aims to identify the potentials of BIM for existing buildings and major bottlenecks of BIM generation procedures considering the LoD and functionalities in O&M lifecycle of building facilities. A systematic analysis through extensive literature review has been done to perceive the knowledge gap between the necessity and existing theories and practice. Finally, the study explores the future opportunities to minimize the knowledge gap and overcome the potential barriers in implementing BIM for existing buildings.

2. Managing building's lifecycle information

The longest phase of the lifecycle of a building is the operation and maintenance and by far the most costly considering the monetary expense for labor and materials in upkeep, maintenance and refurbishment/replacement [17]. According to [18], 85% of the total project cost is spent in operation and maintenance from the owner's perspective. However, traditional practice of information management for O&M is fragmented, manual and tedious leading inefficient O&M and FM of buildings. Particularly, information management suffers following issues that hinder effective O&M.

- Current practice of asset/facility management is paper-based consisting manual inspection and proves to be time consuming, tedious, and prone to humane error.
- Building systems all over the world are becoming increasingly complex with utilization of sophisticated technologies for their operation, building automation, security issues and sustainability, making it challenging for the management and operation of the facility [19].
- According to the "Bureau of Labor Statistics" and [20], maintenance and repair requirements during the life cycle of O&M and FM pose high risk of injuries including falls, electric shocks, crushing, cuts and bruises to the workers as well as facility users.
- Cost effective retrofit for existing building is a great technical challenge considering complex interaction of energy audit system, building performance assessment, cost benefit analysis, risk assessment, and potential of energy savings [21].
- Operation of existing building contributes a large portion of total energy worldwide [22, 23]. Efficient energy use in building is a prime concern in mitigating the stress put on the energy system and bringing positive environmental impact and BIM can significantly improve energy analysis through simulation [24-27].
- Fragmented O&M has made it difficult to do energy simulation, lead error prone decision in retrofit/renovation, safety issues arise in operation, maintenance and repair [28, 29].

Hence, efficient information management for O&M phase of building's lifecycle is utmost important. BIM's dynamic, open access, digital environment and 3D visualization capabilities enable storage, sharing and integration of information for buildings' O&M phase [8].

BIM has been successfully implemented during design and construction as a means of digital database for information management and knowledge sharing between stakeholders, resolving construction schedule conflict and space congestion, enhanced safety through virtual reality and so on. However, use of the same BIM in O&M and FM are still limited considering the inconsistent naming conventions, absence of uncounted number of information necessary for O&M and FM, inadequate methodology to capture existing facilities and asset, and poor information synchronization [30, 31]. COBie (Construction Operations Building Information Exchange) and some other researchers [32-34] have been working on new data standards for BIM project to eliminate the interoperability issues between the model used for design and construction and the model to be used for FM. Nevertheless, all these efforts and BIM adoption have been done for new building construction projects. BIM integrated information management in O&M and FM for existing building is still its infancy.

3. Potentials of BIM for operation, maintenance and sustainability

As mentioned earlier, BIM has been well adopted in design and construction. BIM can be beneficial in O&M and FM phases by many means, such as, better facility management, efficient energy use, cost effective retrofit decision making, safe O&M and repair works, and organized demolition. Table 1 shows potentials of BIM for existing buildings.

BIM enables increased efficiencies in data consistency, single source of information storage and retrieval for FM, reduced effort (time and resource) necessary on finding equipment and material information [34, 41]. Accordingly, information is more easily shared and reused with BIM [3]. It is evident from current literature that the benefits of BIM in O&M and FM are well documented. Nevertheless, lack of BIM for existing buildings is one of the major bottlenecks of the benefits to be realized.

Table 1. BIM for operation, maintenance and sustainability.

Item	Description	Source
Lifecycle analysis	Facility/asset management, monitoring, 3D visualization, real time data access, maintenance schedule, auditing, emergency management	[3, 5, 6, 8, 17, 35, 36]
Retrofit	Retrofit decision making, Repair and reconstruction	[21, 37]
Energy	Building Energy Modelling (BEM), Energy efficiencies and energy conservation	[25-27]
Safety	Safe facility management, hazard mitigation, fall prevention, fire prevention and disaster relief, Integrated Multidisciplinary Model for Security and Safety Management (IMMSSM)	[5, 7, 16, 17]
Sustainability	Sustainable facility management, Sustainable retrofit	[38, 39]
Decommissioning	Analysing material composition prior to demolition	[40]

4. Challenges in creating BIM for existing buildings

Generation of BIM for existing buildings is complex and expensive considering the challenge in capturing building data and high modelling/processing effort required to create a semantically rich BIM. Moreover, the complexity increases with the BIM's level of detail (LoD), intended use, O&M and FM functionalities [10, 12, 14, 42]. As mentioned in [33], increasing effort is required to make a BIM with increasing benefit to be achieved by FM/O&M team which is depicted in Figure 1.

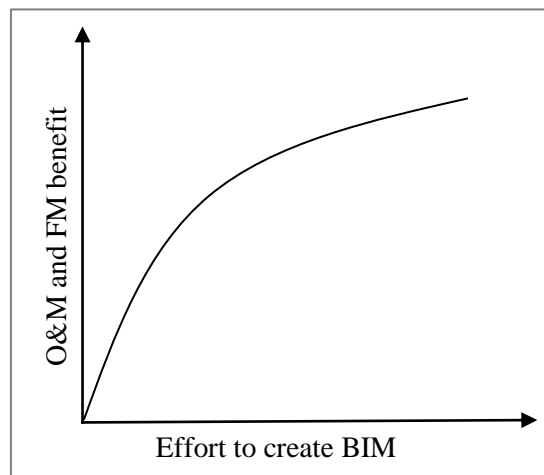


Figure 1. Effort vs Benefit curve (adapted from [33]).

4.1. Data capturing and processing challenges

In this paper we review several different data acquisition technologies used in the industry to support the generation of as-built information for creating BIM: Digital Photogrammetry, Terrestrial Laser Scanner (TLS), and Ground Penetrating Radar (GPR). The typical function of these data acquisition technologies is to capture the geometric information of the object. Digital Photogrammetry works by capturing still images and turning these into 3D point clouds. Laser Scanners use multiple points of

amplified light to measure distances from the scanner to its target. Ground Penetrating Radar use a high frequency radio signal to infer the location of objects embedded.

Current techniques for as-built data acquisition involve laborious on-site surveys with manual measurement or visual assessment [43]. These current techniques suffer from being error-prone and tediously time consuming. The consequence is that such techniques are often unreliable, and create significant uncertainty for decision makers.

4.1.1. Digital photogrammetry: application and challenges. Digital Photogrammetry transforms the still images captured by a camera to derive 3D geometric information. For building applications, terrestrial or close-range photogrammetry is often utilized. At least two cameras with known coordinates are located *away* from an object to create a 3D representation. Mathematically, this creates at least two converging lines to identify a point in space; a technique commonly referred to as triangulation. Typically, this process requires several inputs: The X, Y, and Z coordinates of the location of each camera, as well as ω , ψ , and κ angles of rotation of the camera. Additionally, real-world (common) coordinates represented by control points should also be identified in each image captured, so that the pixel can be recognized.

With today's camera systems, photogrammetry is a relatively inexpensive technology [44]. Several commercially available softwares are available to process digital pictures for building construction applications (e.g. Bundler, Autodesk Remake, etc). The ease of use of this technology has reportedly increased the productivity of survey teams by three-fold [45].

Several problems and challenges exist with photogrammetry techniques. Firstly, digital photogrammetry is sensitive to the changing light conditions. Pictures taken at different times of the day of the same object may suffer from shadows. These shadows may affect the alignment of photos during post-processing. Secondly, image matching is often affected by noise in image sensor of the camera and the presence of occlusions [46]. Thirdly, fixing the absolute scale in digital photographs is a potential major source of error [47]. Lastly, adequate planning is required to obtain accurate models. Ideally, photographs should overlap significantly (some practice professionals use a 60% rule-of-thumb). Photos should also be captured 10 to 15 degrees horizontally or vertically around the object. Also, more photographs will need to be taken if overhangs, protrusions or holes in the building are present.

4.1.2. Terrestrial laser scanning: application and challenges. Terrestrial Laser Scanning is also known as Light Detection and Raging (LiDAR), and LADAR (Laser Distance and Ranging). Both terms refer to a similar technique, with different industrial applications. In general, the technique refers to the emission of pulses of light to the surface of the object of interest. The light is reflected, and a sensor detects the reflected light. The round trip time from the emission to detection is computed, and the distance derived [48].

Newer TLS have features allowing multiple returns of data [49]. At long ranges, the spot size of the TLS increases, because the light emitted from the TLS expands as the range increases, creating the effect of multiple returns. For example, the foliage of the trees will constitute the data of the first return, while the ground below the foliage is the second return of data. Such multiple returns can be important for dealing with partial occlusions.

TLS also has several challenges. Not all objects are suitable for TLS capture; particularly, if an object has a highly non-reflective surface, e.g. black surfaces or rough surfaces, TLS capture quality may be compromised. Secondly, some TLS allow for different selection of wavelengths. The choice of wavelength depends on application. Smaller wavelengths improve the detection rate of smaller objects, while longer wavelengths allow for better penetration through some occlusions. The choice depends on application and on the user's experience. Lastly, the planimetric accuracy of digital photogrammetry is higher, but terrestrial laser scanning can achieve higher accuracy with vertical elevations [50].

4.1.3. Ground penetration radar: application and challenges. Ground Penetration Radar has recently emerged as a complementary tool for acquiring as-built information from building structures. Two

applications of GPR are possible: One, is to use GPR to identify the location of buried utilities [51], and another is to use GPR to inspect concrete structures [52]. As part of this inspection, it is possible to use GPR to locate individual rebars within the concrete structures. Ground Penetration Radar works by emitting a high *frequency* radio signal. The object reflects the signals to the receiver, and the time taken for the pulse to travel to and from the target object is used to infer its depth and location. Depending on the frequency of the radio signal used, GPR can detect objects up to a depth of 30m. Another operating characteristic is the use of either air-launched antennas or ground-coupled antennas [51]. Ground coupled antennas tend to be used for detection of deeper objects, but are typically slower. Air-launched antennas are typically used for shallow ground detection, but is able to cover a larger area.

The utilization of GPR is dependent upon many factors: the depth of the object to be detected, the material of the object, the presence of other sources of interference, and the material of the medium. For example, using GPR in marine clay is known to be limited to a few meters due to the high conductivity of marine clay. The presence of other objects distort the return signal, and increases the noise in the resultant waveform. Lastly, GPR has a relatively high energy consumption profile, limiting its use in extensive field surveys.

4.1.4. Comparison of technologies. Table 2 provides a short comparison of the different data acquisition techniques in the building operations context. It should be noted that each technique has its merits and disadvantages, and future work involving hybridizing or fusing the outputs of two or more techniques to gain a more comprehensive picture of the as-built condition should be explored.

Table 2. Relative comparison of the data acquisition techniques.

	Digital Photogrammetry	Terrestrial Laser Scanning	Ground Penetration Radar
Relative Accuracy	Low (1cm to 1m)	High (1cm to 1mm)	NA
Use in Low-light conditions	No	Yes	Yes
Relative Weight	Low	High	Medium
Relative Cost	Low	High	High
Relative Degree of Expertise	Low	Medium	High

4.2. Functionalities and interoperability issues

Significant advancement has been made in capturing building data and processing technologies to generate BIM for existing buildings. Nevertheless, potential of BIM is yet to be fully realized due to functionalities and interoperability issues. For example, not all O&M related information is compatible for hosting in a BIM environment [8], dealing ambiguity due to incomplete building documentation [33], lack of user-friendly interfaces and incomplete as-is BIM to be used by staff workers in O&M [12] and so on. Moreover, there is hardly a standardized information transfer and storage system available to use BIM for building energy modelling (BEM) [25]. As mentioned by [53], building model and analysis model are separate and restricted by storage format. Furthermore, BIM's information storage capability restricts inclusion of large time series datasets generated by BEM simulations [25]. Hence, it is important to properly identify necessary information to improve the operational performance of building in creating a BIM in operations model [33].

4.3. Collaboration, responsibility and ownership issues

Use of BIM in building's operation and maintenance is very limited till date. There is a clear lack of competent BIM experts in O&M and FM market. Staff workers in O&M phase have limited knowledge and experience of using and updating as-is BIM [12]. Hence, a framework for educating existing O&M and FM personnel is necessary about BIM process and technology [54]. Moreover,

ownership of BIM and responsibilities in managing information must be clearly defined for efficient O&M to avoid any miscommunication.

5. Knowledge gap and future opportunities

The usefulness of BIM for O&M phase has been well acknowledged in literature. Nevertheless, the foremost challenge in realizing potential benefit of BIM for existing buildings is creation of economic and automatic BIM that is compatible for O&M and FM. Moreover, a certain level of BIM maturity should be attained among O&M and FM stakeholders. Quality, accuracy and completeness of a BIM will benefit facility owner with little technical knowledge [54]. It is also important to address organizational challenges that may arise due to the paradigm shift among stakeholders [37]. Furthermore, integration of BIM-GIS would enhance city/country wide energy performance and minimize global greenhouse gas emissions [28].

6. Conclusion

BIM has a great potential for operation and maintenance (O&M) and facility management (FM) of buildings. However, the benefit of BIM has not been fully realized in O&M and FM yet. In part, this is because most of the existing buildings do not have a BIM and creating a BIM for existing building is challenging. This paper has explored the current state of BIM for existing buildings in terms of potential opportunities and major bottlenecks in creating a semantically rich as-built BIM. As can be seen, BIM can be beneficial in O&M and FM phases by many means, such as, lifecycle analysis for better facility management, sustainable and efficient energy use, cost effective retrofit decision making, safe O&M and repair works, and organized demolition. To realize these benefits researchers have been working to create as built BIM for existing buildings. Current techniques used for as built data acquisition are mainly digital photogrammetry, terrestrial laser scanning, ground penetration radar. These techniques involve laborious on-site surveys with manual measurement or visual assessment, error-prone, tediously time consuming, often unreliable, and create significant uncertainty for decision makers. Moreover, creating BIM from the captured data requires high conversion/modelling effort from skillful personnel. The usefulness of BIM is further challenged by functionality and interoperability issues, lack of user-friendly interfaces and incomplete as-is BIM to be used by staff workers in O&M, and lack of competent BIM experts in O&M and FM market. Hence, there is a great potential of research opportunities in creating economic and automatic BIM for existing building and attain certain level of BIM maturity among O&M and FM stakeholders. Furthermore, a framework should be developed to educate existing O&M and FM personnel about BIM process and technology.

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