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Using BIM to Retrofit Existing Buildings

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Abstract

A large number of ongoing research programs are looking into the implementation of Building Information Modelling (BIM) platforms to optimize design and construction processes. BIM based tools (e.g., Bentley AECOsim Building Designer, Tekla Structures, Autodesk Revit's Architecture, Structure, MEP, and Navisworks) can handle numerous types of data input (e.g., 3-D design, energy models, schedules, cost estimates) and offer rigorous simulation and visualization options in an integrated manner allowing engineers and contractors to track and control their projects effectively. A similar set of research projects are investigating the use of sustainability principles (e.g., waste reduction, energy savings, healthy indoor environment) to optimize the management of projects throughout design and construction. The link between BIM and sustainability has been flagged in the literature especially in energy-driven retrofits. Nonetheless, the application of BIM to retrofit existing buildings faces challenges which could be due to the multi-disciplinary nature of information exchange, the timeliness of the exchange, and the wide array of technological components that are needed to ensure an optimal exchange. This paper describes, through a critical review of the literature, the areas which are mostly covered under BIM and sustainability. The purpose of this paper is to examine the overlap between the two topics where BIM offers a platform for reducing energy consumption in existing buildings. Finally, a research agenda on enhancing the role of BIM in energy-driven renovations is proposed.

Keywords: BIM; sustainable construction; energy modelling; refurbishment; existing buildings

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1. Introduction

The BIM Handbook defines Building Information Modeling (BIM) as ‘‘a modelling technology and associated set of processes to produce, communicate, and analyze building models’’, where building models are digital objects associated with computable graphics, parametric rules and data attributes [1] which could be managed, shared and exchanged in an interoperable way. Watson offered two definitions of BIM: a) a noun that describes a particular set of engineering software and b) an adjective that describes a process of information management and adoption [2]. Regardless of its definition, BIM is believed to offer tools that could be utilized for all project management domains, by all stakeholders, and across the whole project lifecycle [3]. A survey by McGraw-Hill in 2009 provided feedback on the adoption of BIM technologies in the construction industry. For example, 72% of BIM users reported an effect of BIM on enhancing their project processes, and 62% of these users use BIM on more than 30% of their projects [4].

This paper explores the relationship between BIM and sustainability, which is another emerging concept in the construction industry. Sustainability advocates the efficient use of natural resources while maintaining low operating costs and waste production [5]. Specifically, the paper sheds light on energy-driven renovations in existing building which is an area of overlap between sustainability and BIM. However, deploying BIM tools to achieve sustainable goals of refurbishment encounters serious challenges. Hence, the paper offers suggestions for future research agenda to facilitate the use of BIM tools for energy-driven retrofits of existing building.

2. Methodology

To achieve the objectives of the study, a thorough review of literature was carried out. This includes reviews of several databases such as Scopus, ScienceDirect, Engineering Village, Google Scholar, and ASCE library. Keywords related to BIM and sustainability were chosen. As a result, a total of more than 200 relevant readings was obtained, reviewed and arranged into group of dominant themes. A theme, in this paper, is defined as a focus area or the main idea the paper revolves around. For example, the themes related to elements of sustainability (e.g., water, indoor environmental quality, energy, materials and waste reduction). Due to paper size limitations, only a subset of the collected papers is cited.

3. Sustainable Construction

The methodology described above yielded 102 relevant papers which were arranged into the following dominant themes: water, energy, waste reduction and materials, and indoor environmental quality. These themes were inspired from the credit categories of LEED and BREEAM, which are some of the most widely used rating systems to assess sustainability of buildings. Figure 1 provides a frequency diagram of these themes. The total number of 110 is due to the fact that some articles had more than one dominant theme; thus, were counted more than once. For instance, energy analysis is often examined in the context of various building materials. Hammond and Jones [6] developed a database for embodied energy and carbon emissions for almost 200 different materials. Similarly, Gustavsson and Sathre [7] compared wood and concrete in terms of energy and net CO_2 emissions. As a result, these two articles fell under two categories, namely “Energy” and “Waste reduction and Materials”.

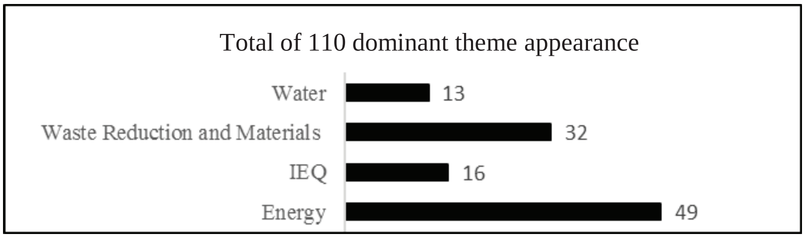

Fig. 1. Frequency diagram of dominant themes in the reviewed literature on sustainable construction

From the peer-reviewed literature, the most dominant theme appears to be about Energy (49 times). Life cycle energy analysis and low energy buildings are gaining popularity in the literature [8]. The high frequency of the energy theme indicates a growing awareness of the detrimental impact of energy consumption on the environment through carbon emissions. Energy consumption rates are alarming; hence, mitigation measures are needed to reduce carbon emissions and preserve natural resources for longer periods.

4. Building Information Modeling

A similar method was used to explore the stat-of-art literature related to BIM. Overall, 111 papers were reviewed and grouped into 10 different focus topics shown in Figure 2. These are communications, integration, cost, human resource, procurement, quality, risk, scope, stakeholders and time management. These topics are in-line with the 10 knowledge areas described by the Project Management Institute (PMI)'s book of knowledge.

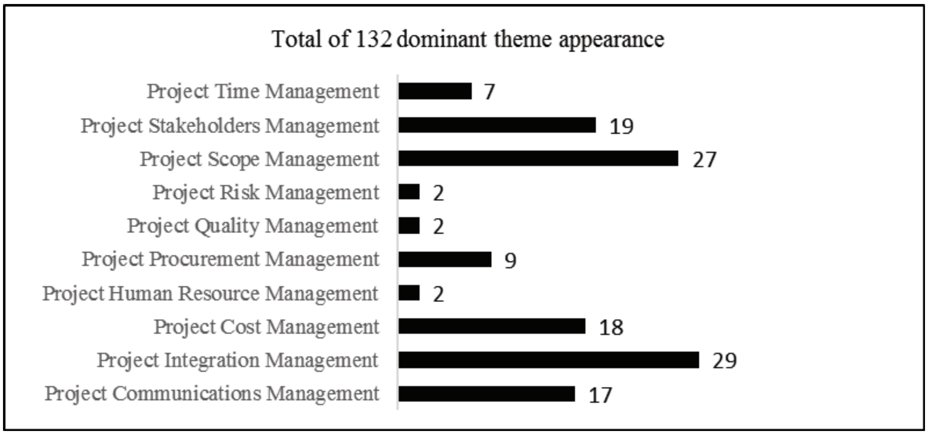

Fig. 2. Frequency diagram of focus topics in the literature on BIM.

The frequency diagram shows a total of 132 BIM related topics in the literature indicating that some of the papers had more than one focus topic. For instance, Lin and Su [9] proposed a BIM Facility Maintenance Management (BIMFMM) system for maintenance staff to follow up and update maintenance in a digital format. This publication addressed both the scope of BIM as a visual tool for FMM, and the stakeholders (i.e. maintenance staff) who use the tool. Another example is the cloud-based BIM performance benchmarking application called BIM Cloud Score (BIMCS) presented by Du, et al. [10] to evaluate an institution's performance in BIM utilization. The article focuses on both data obtained from stakeholders and their integration.

The most frequent topics in the reviewed literature on BIM related to Integration Management (29) and Scope Management (27). They are followed by Stakeholders Management (19), Cost Management (18), and Communication Management (17).

Integration, which has the largest frequency among all other topics, includes collaboration and BIM implementation topics. Grilo and Goncalves [11] discussed various aspects of BIM which make it a collaborative environment. Aram et al. [12] created BIM based decision frameworks to integrate construction supply chain design and delivery processes. Kim, et al. [13] developed a physical BIM library to be used for thermal energy simulations; while Karan, et al. [14] worked on integrating BIM and GIS using semantic web technology. Lin, et al. [15] built a web-based BIM tool for Process Management (conBIM-PM) and used it to store as-built drawings, as well as to trace and manage BIM models.

Integration also includes a wide range of literature focusing on BIM implementation. This is done qualitatively through studies (e.g., Azhar [16]) describing the benefits and challenges of BIM implementation. Miettinen and Paavola [17] offered additional insight on enhancing BIM implementation. These articles emphasize the importance of training and education for an effective implementation of BIM. Other papers suggest frameworks to apply particular BIM standards [18]. Succar [19] suggested an approach for competency assessment, acquisition and application. Quantitatively, a structural equation model (SEM) was used by Lee, et al. [20] to study BIM acceptance and use. Quantifying the benefits of BIM offers significant incentives for stakeholders to implement BIM in practice.

The second focus topic, i.e. Scope Management, includes many sub-topics such as design and construction management which correspond to the major phases in a project lifecycle. BIM has been used to automate the process of assessing and checking design against specific criteria [21]. Along the same lines, Kaner, et al. [22] shed light on the enhancement of the quality of precast design. The advantages and disadvantages of BIM in preparing, revising and coordinating designs were also explained by Maia, et al. [23]. In construction, Lu and Li [24] advocated the use of BIM to optimize field work. BIM is often perceived as a learning tool for construction management activities such as safety, scheduling, procurement, and cost controls [25].

The high frequency of Integration and Scope Management appearance in the literature highlight the opportunity of using BIM technologies to manage construction projects while integrating BIM tools with the needed simulation software.

5. Overlap Between BIM And Sustainability

As mentioned earlier, Energy gained the most momentum under sustainable construction. Under BIM themes, Project Scope Management and Project Integration Management gained the most attention. A possible overlap between the two concepts resides in the usage of BIM for energy modelling and subsequently defining the scope of retrofit of existing buildings. Facilitating energy-driven refurbishments of existing buildings through BIM technologies will help achieve sustainability ratings and certifications in shorter period of times.

Besides using BIM as a strategy to facilitate the analysis of energy performance of existing buildings, the literature provides other methods for achieving energy driven renovations. For instance, energy audits can be utilized for refurbishment of existing buildings to identify the energy usage and the associated costs with retrofitting [26]. The advancement of energy audit technologies offer more reliable information [27]. For example, Building Automation Systems (BAS) and Building Energy Management and Control System (EMCS) offer data that can be deployed for calibration of the parameters in an energy simulation model [28]. The accuracy of the collected data directly affects the reliability of the energy analysis for retrofit purposes [29].

Another strategy used to analyze refurbishment options is the environmental assessment tools [30]. These tools provide frameworks to check and enhance the energy performance of existing buildings. Performance assessment tools have gained popularity with the development of rating systems which benchmark energy performance of existing buildings against quantitative and qualitative performance indicators [31]. Other literature work describes the prerequisites, credits, and measurement methods required to achieve a certification for a refurbished building [32]; while others [33] quantified the financial benefits of improving the environmental performance of existing buildings.

In addition to the strategies provided by advanced energy auditing technologies and environmental assessment frameworks for refurbishment of existing building, computer simulation software can be used to model and simulate the energy performance of retrofit measures [28]. Some examples of these energy simulation platforms are EnergyPlus, eQUEST, BLAST, TRNSYS. For instance, Bojić et al. used EnergyPlus to analyze the energy consumption in a thermally non-insulated old house before and after renovation for single and combined refurbishment measures in Belgrade, Serbia [34].

Based on the literature review and discussions with energy modeling experts, a simplified process for an energy-driven renovation using BIM technologies was put together. The process which is depicted in Figure 3 has three major stages.

6. Setting Up An Agenda For Future Research

Although there is an important overlap between sustainability and BIM manifested in energy-driven refurbishment projects, there is a need to further examine this area. The literature suggests little maturity in deploying BIM to retrofit existing buildings. The following section offers a research agenda to enhance the applicability of BIM tools in energy-driven building retrofit projects. The agenda is organized based on the technical, informational and organizational needs.

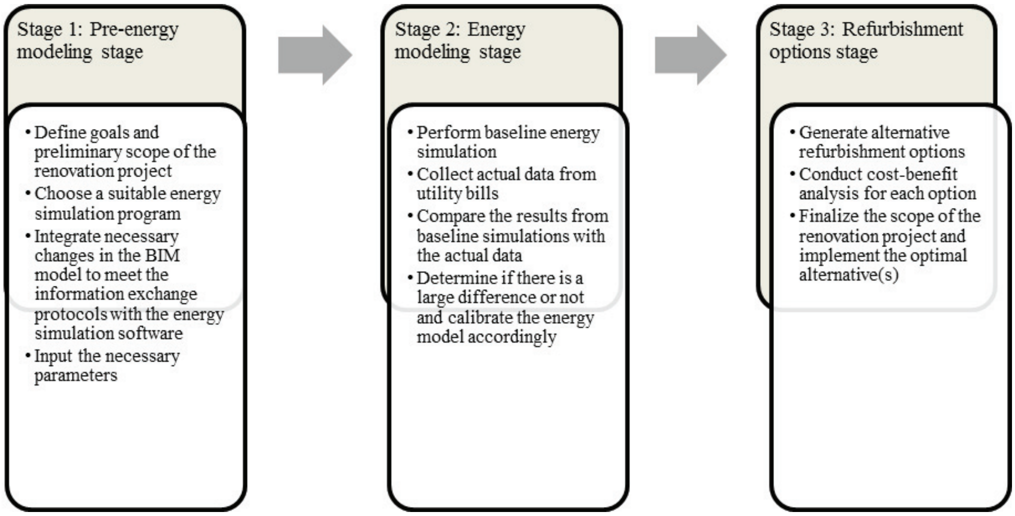

Fig. 3. Process Chart of Steps to perform energy-driven refurbishments for existing buildings using BIM

6.1. Technical Needs

The technical needs of BIM in energy retrofitting projects are numerous and are divided based on the stages of the project: Pre-Energy Modelling, Energy Modeling, and Refurbishment Options.

6.1.1. Pre-Energy Modelling Stage:

The technical needs in the pre-energy modelling stage depend on the availability of a BIM model. If a model is available, facility managers can typically use it for energy simulations after the necessary updates. However, the interface between BIM platforms and energy simulation software is still complex because of incompatibility in information exchange protocols. Future research may focus on ensuring a smooth translation from BIM to the selected energy simulation software. Researchers can possibly create algorithms to automate rules for the exchange protocols. Other research possibilities entail programming review checks for compatibility with energy simulation software.

If there is no available BIM for the existing building, facility managers shall collaborate with BIM modelers and architects to build one for energy refurbishment purposes. Developing the model from scratch requires a significant data collection effort. The future works can be directed to automate the process of capturing as-built information, integrating it into BIM databases, or even modelling volumetric BIM objects. Moreover, there is an arising need to build special techniques for restrictions in field operations and their processing into BIM, especially in concealed or distorted areas of existing buildings. The usage of laser scans and photogrammetry technologies can contribute through materials and textures identification.

6.1.2. Energy Modeling Stage:

At energy modeling stages of refurbishment projects, the research may focus on the calibration of the baseline energy simulation model. For instance, there is a need to create systems in BIM platforms that calibrate the energy simulation using data from actual utility bills. Algorithms are needed to decide on the acceptable margin of difference between the actual results and the baseline models. The decision on the acceptable deviation margin between actual bills and simulation results has been a challenge for energy modelers. Therefore, setting standards will facilitate the work of the modeler and streamline the process of calibration.

6.1.3. Refurbishment Option Stage:

The technical needs extend to the third stage, i.e. selection of refurbishment options. The modelers face challenges in choosing the optimal refurbishment method because of uncertainty in the data. There is need for mature BIM tools to allow modelers to handle uncertainties better. In particular, properties of time and money, source properties, and products properties should be programmed into BIM. Properties of time and money are related to the costs of material, idle times, and project overhead associated with every refurbishment option. Source properties clarify the energy consumption as well as the treatment and maintenance that each option requires. Additionally, product properties indicate the amounts and types of wastes produced. Product properties specify the amount of recyclables and the type of emissions (e.g., dust, noise, vibrations). Integrating all three property types in BIM provides a solid decision platform for an energy-driven retrofit project. The decision should be based on a detailed cost-benefit analysis that includes environmental considerations (energy savings) as well as economic factors such as return on investment or payback period.

6.2. Informational Needs

There are challenges in interoperability that hinders exchange of building data across BIM platforms [35]. Although universal data structures are continuously improved, developed concepts such as Information Delivery Manual (IDM) and Model View Definition (MVD) focus on newly constructed buildings rather than existing buildings [36]. Although the Construction Operations Building information exchange (COBie) standard includes material and sustainability information necessary for energy modelling, it excludes information on architectural parts (e.g., slabs, walls, footing, roof, and stairs) that are required for refurbishment [37]. COBie also excludes flow segments and fittings which are necessary for separation of components during refurbishment projects.

An additional informational need is a proper management of chronological data and their transaction and synchronization into BIM [38]. This need arises from the rapid BIM technology development besides the high demand on semantic web technologies. As BIM's technical functionalities mature, the information exchange protocols must mature in parallel to aid the implementation of BIM in any energy simulation software.

6.3. Organizational Needs

In various countries the usage of BIM is encouraged through political pressures and legal frameworks such as public tendering [39], while in other countries the application of BIM is still lagging behind. Several improvements are possible for BIM's implementation in the life cycle of a construction project especially in the operation and maintenance stage.

There is a need to develop legal instruments in order to standardize the model ownership and data responsibility, liabilities, and fees. This will facilitate BIM implementation for existing buildings refurbishment projects and will enhance data security and users' confidence [40]. Some of the most important legal instruments to organize projects for existing buildings are contracts. In this context, innovative project delivery approaches such as Integrated Project Delivery, have built a collaborative environments to construct new buildings where the designer, contractor, subcontractors and suppliers work for the overall benefit of the owner [41]. Refurbishment in existing buildings needs the development of similar contractual agreements which in turn motivates the usage of BIM tools.

Facility managers, energy experts, and consultants typically resist the changes that require them to deploy new concepts and technologies, such as BIM. Therefore, in addition to the legal instruments, it is necessary to raise stakeholders' awareness about the benefits of BIM technologies. Training and education on how to implement these technologies for energy-driven refurbishments in existing buildings are needed to collaboratively organize the project and achieve optimal results.

7. Conclusion

This study summarizes recent literature on two emerging fields of research, BIM and sustainability. Under sustainability, Energy seems to have gained the most momentum compared to other themes such as Materials and Water. With regards to BIM, Integration and Scope Management were the most frequently covered topics in the literature. The review indicates a significant area of overlap between BIM and sustainability in the usage of BIM to define the scope of energy-driven retrofits of existing buildings.

There is a consensus across the reviewed studies that BIM is still immature for its full adoption in refurbishment projects because of technical, informational and organizational complications. The technical challenges are mainly revealed in the automation of data capture for BIM creation, maintenance and updates for a pre-existing BIM model, as well as in handling uncertain data. Proper data management and interoperability are the most serious informational challenges. Adaptation of legal and organizational frameworks is necessary to standardize implementation of BIM tools in existing buildings. These challenges offer opportunities to embark on research to improve the utilization of BIM for energy-driven refurbishment projects.

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