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Application of Green BIM enabled Tool for Developing Sustainable Building Process

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Abstract

Within the last decade, the building industry has witnessed an expanding blossom of applying and developing building information modeling (BIM), as an emerging, promising, and innovative technology and process, dramatically transforming the way of constructing environmentally sustainable building from the original conception onwards to demolition. However, research concentrated on showing a clear understanding of utilizing BIM-based tools to achieve environmental sustainability of a building throughout its lifecycle is scarce. This paper aims to provide a systematic review of existing papers in the field of green BIM and identify major directions for future research agenda. It is supposed that green BIM perceived as a solution to numerous inefficiencies of managing environmental impacts and sustainable analysis of a building should not only be limited to the design and construction stages, but extend to the operation, maintenance and demolition stages over its entire lifecycle. Based on a comprehensive review of green BIM related issues, five main stages of a building's lifecycle are identified. The limitations of green BIM adoption are discussed and future research directions are proposed. It is supposed that future application of BIM should resort to reduce, reuse and recycle strategies for sustainable purposes. Developing a more comprehensive and inclusive green building certification systems worldwide is demanding. The system should streamline the process of integrating BIM into energy analysis software for more efficient management of low energy consumption and minimal carbon emissions. More efforts should be exploited to develop a real-time monitoring and tracking technique for managing carbon emissions from construction activities in different stages. This research may establish a preliminary framework of enhancing environmental sustainability over building life cycles through green BIM. Beneficial outcomes can be a stimulating factor facilitating building construction practitioners implementing green BIM tools for sustainable purposes.

Keywords: Building information modelling, Green BIM, Green building, Building environmental sustainability, Building energy performance

1. Introduction

In recent years, the term 'environmental sustainability' has gradually arisen a growing concern in both construction industry and academia, for it can be utilized as a revolutionary way to transform traditional built environment (Wong and Zhou, 2015). Driving by the increasing pressure of improving energy efficiency (Wong and Kuan, 2014), over the recent decades, the architecture, engineering, and construction (AEC) industry has long been making full efforts to seek effective approaches to minimize energy consumption, mitigate greenhouse gas (GHG) emissions, and alleviate resource depletion (Wong et al., 2013). Despite of these endeavors, the AEC industry has frequently been criticized for its poor and inefficient monitoring and management of greenhouse gas (GHG) emissions and energy consumption (Wong et al., 2013). For example, according to Council (2008), the building industry accounts for 39% of energy consumption, 38% of carbon dioxide emissions, and 40% of raw materials depletion in the US. Therefore, enhancing the sustainability of built environment is receiving increasingly pressing challenges to achieve both economic and environmental friendly effects (Azhar et al., 2009, Azhar et al., 2011, Wong and Zhou, 2015).

For achieving sustainable development purposes, an emerging, promising, and innovative information technology, such as BIM, has dramatically altered the way of a building from the original conception onwards to demolition (Hardin, 2011, Azhar et al., 2012). As BIM allows multiple disciplinary information to be encapsulated within one model, it is believed that BIM serves as a dynamic repository for building performance assessment and sustainability strategies analysis throughout buildings' life-cycle (Schlueter and Thesseling, 2009, Azhar et al., 2010, Azhar et al., 2011, Olawumi and Chan, 2018).

Despite a large amount of literature on BIM implementation in the AEC industry over the past decade, research topics on the application of building information modeling tool for enhancing environmental sustainability over buildings' life-cycle are scarce. Additionally, there is a lack of systematic and comprehensive review of green BIM related issues and its full potential is yet to be investigated to meet the demands of constructing a sustainable AEC industry. Thus, this study attempts to examining the existing green BIM research, identifying the main research domain and in-depth exploring its potential application in enhancing environmental sustainability. This will help enrich the body of knowledge on green BIM and propose a new direction for future research agenda.

2. The Rise of Green BIM

Sustainable construction can be defined as a way of constructing a healthy built environment with minimization of energy consumption, maximization of resource reuse, and maximum usage of renewable and recyclable resources (Rajendran et al., 2012). As reported by Schlueter and Thesseling (2009), building operation encompasses 40% of global energy consumption and co_2 emissions, and accounts for 30% of GHG emissions. In order to overcome the increasing environmental concerns and the rising cost of energy, including climate changes, greenhouse effect, and energy crisis, regulations around the world have initiated diversified environmental assessment tools for establishing sustainable built environment with the aim to developing energy efficient and environmentally responsible buildings (Azhar and Brown, 2009, Azhar et al., 2009, Azhar et al., 2010, Azhar et al., 2011, Wu and Chang, 2013, Bank et al., 2011). Energy efficient building and environmental assessment can be evaluated by different rating systems from various countries and areas (Doan et al., 2017), for instances, Leadership in Energy and Environmental Design (LEED) and Energy Star in the US, Green Globes in the US and Canada, Building Environmental Assessment Method (BEAM) Plus in Hong Kong, Building Research Establishment Environmental Assessment Methodology (BREEAM) in the UK, Green Star and National Australia Built Environment Rating System (NABERS) in Australia (Gandhi and Jupp, 2014), Green Mark Scheme in Singapore, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan, the Ratio of Equivalent Transparency in Taiwan (Wu and Chang, 2013) and the Green Building Index (GBI) in

Malaysia (Zuo and Zhao, 2014). Different green building assessment tools reveals that industry expectation for Green BIM practice is increasing. Architectures and designers have also striven to find out a way to monitor and minimize energy consumption and GHG emissions.

In order to cope with the increasing concern of resource depletion and to address environmental considerations in both developed and developing countries, BIM can be applied as an efficient and integrated tool for improving sustainability in the AEC industry. As the concept of green BIM continues to gain momentum, numerous previous studies have been placed on green BIM practices. Schlueter and Thesseling (2009) developed a BIM-based model for energy and thermal simulation. Welle et al. (2012) employed a method to automatically integrate daylighting simulation into a BIM model within multidisciplinary design optimization environments. These efforts are made by the AEC practitioners to construct a green building with low energy consumption and least environment impact (Azhar and Brown, 2009, Wu and Chang, 2013). As indicated by Wu and Issa (2013), current practical experience of green BIM utilization is immature and unsystematic. Opportunities can also be found to analyse and assess environmental effects of a building over its entire life (Wu et al., 2014). Wu et al. (2012) has proposed a life cycle assessment model to identify and evaluate energy consumption and CO_2 emissions of office building. Lu et al. (2017) has proposed the potential usage of BIM software in supporting sustainable analysis in the process of green building assessment. In conclusion, BIM-enabled tool can be used as a real-time interactive and integrated system from the initial design stage, to construction, operation, maintenance, renovation, through to demolition (Lu and Li, 2011, König et al., 2013).

3. Research Methodology

In this study, a comprehensive literature search based on the ‘title/abstract/keyword’ search method was first conducted through the commonly applied search engine, Scopus, to identify the published research paper relating to green BIM. The keywords used in the literature search included green building information modelling, building environmental sustainability and building energy performance. Refereed journals or refereed conference proceedings with these specific terms in their titles, abstracts or keyword lists were considered to satisfy the requirements of this study. As green BIM is a relatively new technological advancement, this review surveyed articles published between 2004 and 2018. The search indicated that the most frequently cited journal was *Automation in Construction* (with 14 studies). Some of the top journals included in this literature search were *Automation in Construction (AIC)*, *Waste Management (WM)*, *Journal of Construction Engineering and Management (JCEM), Building and Environment (BE),* etc. The identified papers were categorised according to the key stages of building life-cycle. These stages included: design stage, construction stage, operation stage, maintenance stage, and demolition stage. The following section will discuss the application of green BIM in different stages over building’s lifecycles.

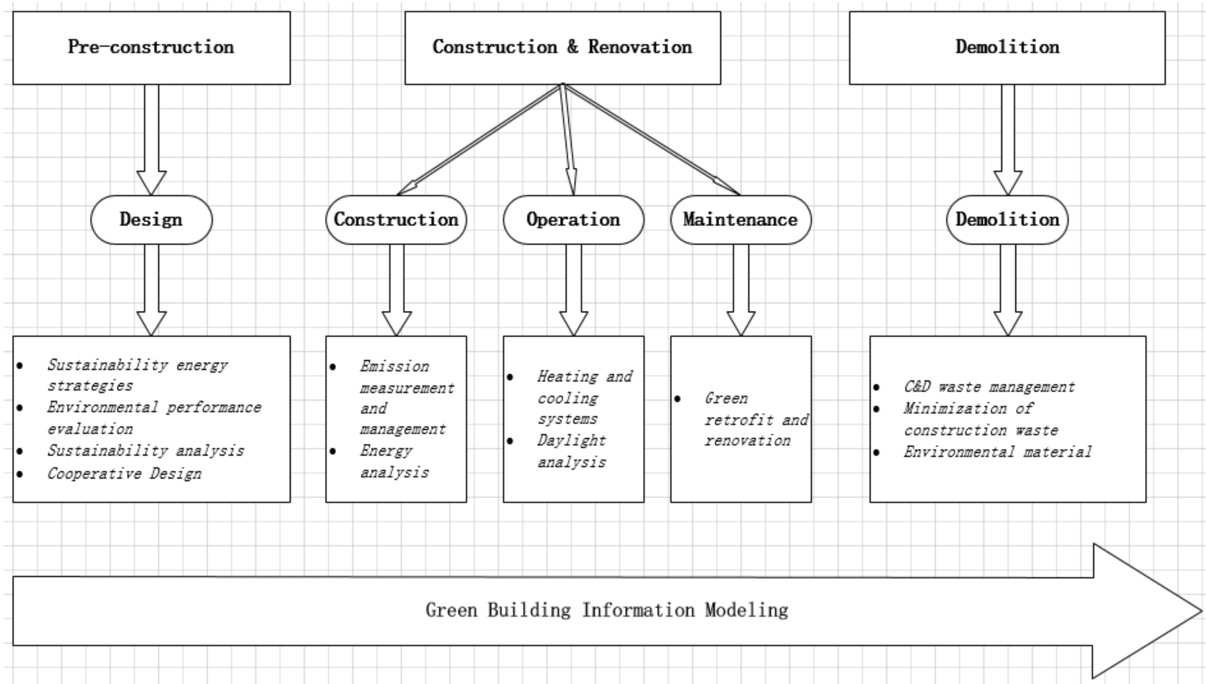

Figure 1: Green BIM applications over building life cycles

4. Research Findings

4.1 Design Stage

As pointed out by Azhar et al. (2009), the early design and preconstruction stage are perceived as the most effective way to construct an energy efficient building in terms of sustainability, energy-saving, and environmental sound benefits. Sustainable design strategies can be integrated into the initial conceptual design stage, which would have substantial impact on building performance of a facility (Azhar et al., 2010). With taking numerous diverse factors into account, green building design phase is usually supposed to be a more complicated process than that of traditional ways, which should integrate and address large amount of information associated with sustainable elements and environmental data (Gandhi and Jupp, 2014). Conventional design approaches, however, provide limited support to allow the designers to visualize the feasibility of such early decisions. This failure to analyze sustainability on a continuous bases during the design phase resulting from inefficient process of retroactive modification of design to achieve a series of performance criteria (Azhar et al., 2010, Schlueter and Thesseling, 2009). As BIM can be used as a tool for evaluating a building's environmental performance at the beginning design stage, it supports the possibility of determining strategies relating to sustainable design (Azhar et al., 2010). More specifically, BIM can store the entire design information into a share and open repository effectively to achieve integration and uniqueness of information. Also, synchronized information with regard to energy use, embodied energy, building performance data can be obtained by applying BIM in order to fully accomplish specified progress (Inyim et al., 2014, Lu et al., 2017).

With the development of information technology and wider implementation of BIM, a number of studies have been demonstrated the capability of BIM in aiding sustainable design decisions. For example, Yoon et al. (2009) proposed a BIM-based model for energy-saving concept to develop energy efficient building with low energy consumption. It also introduced the design technique with high-efficient, low-energy performance based on the BIM technology. Azhar et al. (2011) developed a conceptual framework identifying the relationship between BIM based sustainability analyses and the LEED certification process. This research also investigated whether LEED credits can be directly or indirectly prepared using BIM software and streamline the process for saving time and resources. Nguyen et al. (2010) established a sustainability evaluation framework for architectural design on account of BIM technology, which allows the user to export the model into analysis tools for sustainability analysis. Wong and Kuan (2014) also investigated the potential application of BIM for improving energy efficiency in terms of residential building project in order to achieve BEAM Plus sustainable building certification in Hong Kong.

4.2 Construction Stage

Construction processes place great pressure on environmental sustainability with the fact that the construction sector is the third highest producer of GHG emissions among industries (Heydarian and Golparvar-Fard, 2011). The need for low-cost and effective monitoring of construction-related emissions stands out (Wong et al., 2013). Compared with the investigation of BIM in the design phase, less efforts have been made to achieve low carbon emission with greener construction site activities (Mah et al., 2011). However, the application of BIM for measuring and monitoring carbon emissions during the construction stage is also having great significance (Mah et al., 2011).

Several researchers investigated emission estimation from construction stage and their impacts (Guggemos and Horvath, 2006, Koo et al., 2009, Ahn et al., 2009, Shiftehfar et al., 2010). For example, Li et al. (2012) integrated BIM techniques and the carbon emission and energy analysis tools to develop the computational model of carbon emissions, in which the calculation principle, the basic database, and each process of modelling are included. With the aim of identifying existing gaps and new studies, Ding et al. (2014) developed a BIM application framework for the domains of quality, safety and environmental management. It is suggested to expand 3D to computable nD during the construction phase. In terms of residential buildings, a baseline of CO_2 emission quantification was developed by introducing a 3D BIM system. The findings unfold that the operation of construction equipment on-site, transportation and heating for curing concrete are the primary emitters during construction process (Mah et al., 2011).

Some studies on green BIM were conducted by integrating design stage with construction stage. For example, Bynum et al. (2012) investigated the application of BIM for combining sustainable design with construction among designers and constructors. The findings indicate that the beneficial project delivery approaches for utilizing BIM as a sustainable instrument are the design-build (DB) and integrated project delivery (IPD) model. Some studies include other tools when it comes to improving environmental sustainability of construction. For instance, an integrated GIS and CAD-based approach for visualization, communication, and greenhouse gas emission analysis was proposed for graphically showing the spatial aspects of construction (Hajibabai et al., 2011). As for BIM data collection, it always stops at the pre-construction stage. Therefore, it is suggested to modify BIM procedures and software to include the construction process documentation (Goedert and Meadati, 2008).

4.3 Operation Stage

Wu et al. (2014) stated that the building operation comprises the largest share of total energy consumption over its entire life cycle, which produces one-third of building's carbon emission. Gerilla et al. (2007) also explored that emissions from carbon dioxide were the greatest in the operation stage, accounting for 79% of the total emissions, while the remaining phases such as construction, maintenance and demolition only had 21% the total carbon emissions. This was primarily contributed by the heating, ventilation and air conditioning (HVAC) systems, which contribute to nearly 50% of energy in buildings and consume 10-20% of total energy use (Pérez-Lombard et al., 2008). Thus, there is a great need for improving building operation management through energy-saving approaches without compromising environmental sustainability.

Current application of BIM as an analysis tool for managing environmental performance during the building operation includes 1) the analysis of heating and cooling requirements, for instance, reveal that energy consumption is reduced up to 10% through applying thermostat operation mode, lowering total cooling energy consumption, and improving the efficiency of cooling power (Tzivanidis et al., 2011, Chen, 2018); 2) identifying the daylighting opportunities and reducing the electrical lighting load and subsequent heat and energy loads. For example, as demonstrated by some professionals, daylight can be improved with minimal glare in case the window were suitable for light shelves (Novitski, 2009). 3) Selecting major building equipment that may reduce energy use. Detailed energy simulation is a promising efficiency improvement approach for evaluating practical energy consumption (Novitski, 2009, Chen et al., 2017). In addition, Costa et al. (2013) describes an innovative integrated toolkit designed to assist energy managers to systematically monitor and manage energy consumption of a building in the operation phase. Building combined heat and power (BCHP) could be of assistance for improving energy efficient building development with reduced carbon emissions.

4.4 Maintenance Stage

Building maintenance was defined as "work undertaken in order to keep, restore or improve every part of a building, its services and surrounds, to a currently acceptable standard, and to sustain the utility and value of the building" (Seeley, 1987). Based on British standard, it is the combination of different technical and administration actions to maintain a physical asset in, or restore it to a condition in which it can deliver a required function (BSI, 1993).

During this stage, retrofitting/renovating existing buildings can make a difference on environmental sustainability by conserving natural resources and reduce energy consumption (Wong and Zhou, 2015). Some scholars have investigated the functionality of BIM in retrofit/refurbishment/renovation planning and execution (Penttilä et al., 2007, Becerik-Gerber et al., 2011, Yee et al., 2013, Donath and Thurow, 2007). The utilization of BIM that would be applied to deliver sustainable design concepts into retrofit were explored (Hammond et al., 2014). It could aid in the collaboration of various fields in the early phases before renovation. BIM could also act as a newly established platform for conducting energy analysis, addressing clashes from diverse data sources, assessing and monitoring building performance during the process of renovation. These features and benefits make BIM as a powerful toolkit for applying sustainable design thoughts into building retrofit/renovation (Hammond et al., 2014). Some researchers gave their focuses on details of BIM applications in green retrofit. For example, a series of 3D models were constructed to capture the feasibility of green roof retrofitting for existing buildings in an old district of Hong Kong. And the researchers investigated the overshadowing of the building blocks including their orientations and proximities to neighboring taller buildings (Wong and Lau, 2013).

4.5 Demolition Stage

Compared to other stages of a building's life cycles, the application of green BIM on the environmental performance of demolition stage of a building is relatively limited. However, grounded on the escalating concern of construction and demolition (C&D) waste, construction waste management is receiving increasingly pressing challenges to achieve both economic and environmental friendly effects (Yuan and Shen, 2011, Lu and Yuan, 2011, Yuan et al., 2011). For example, in U.S., construction and demolition(C&D) debris was considered as the main elements of non-municipal solid waste, and nearly 136 million tons of debris was generated by construction related C&D waste (Wang et al., 2004). Also, as evidenced by Minks (1994) approximately 20% of solid waste was produced by C&D waste in the U.S. The same problem arose in the UK, that over 435 million tons of waste was produced per year (Baldwin et al., 2008), generating around 70 tons of waste originating from C&D materials and soil (Yuan et al., 2011).

These large amounts of waste coupled with limited landfill capacity posed a great challenge on most of countries and areas. Additionally, C&D waste may decrease land resources because of waste landfilling, deplete natural resources, generate harmful noise and air pollution, create noxious soil and water resources, etc. (Hamidi et al.). Consequently, improvement of C&D waste management for diminishing and minimizing construction waste are perceived as an emergent need to reduce its negative and detrimental impacts on the environment (Hamidi et al., Wang et al., 2004, Begum et al., 2006). Several previous studies have been investigated and placed on the construction waste management for environmental benefits. Extending the life-long duration of landfill sits and decreasing primary resource requirements have been regarded as the major environmental benefit of waste reduction (CIRIA, 1993). As indicated by Lingard et al. (2000), instead of developing new undesirable landfills, waste reduction was obviously considered as an economical approach to eliminate potential environmental destruction.

Researchers have been exploring BIM application in the demolition stage of C&D waste management. For example, in terms of minimization of construction waste, Porwal and Hewage (2012) proposed a model, which is integrated with BIM, to simulate architectural and structural design requirements and compare results to facilitate minimizing rebar waste during the design process. A high potential of cost reduction was identified by a two-story reinforced concrete structure that utilized this approach. Akbarnezhad et al. (2014) developed a framework as well as a systematic approach that utilized a set of database provided by BIM to identify and compare diverse demolition strategies on costs, embodied energy and carbon emissions of construction. It provides decision makers a relatively easy way to assess and select the most appropriate demolition strategies applicable to a specific project for achieving environmental and economic consequences. Hamidi et al. (2014) focused on three demolition waste management methods by using BIM technology in order to provide decision makers a more reliable and accurate information of cost-benefit analysis model. A subsequent case study was investigated to demonstrate the latent application of BIM-based system in fostering cost-benefit evaluation in deconstruction stage. Also, the cost of waste recycling and reusing was required to estimate for measuring the gains from reselling the recyclable materials. Some even explored the implementation of BIM in reducing demolition and renovation waste. For instance, a BIM based system was developed for calculating and managing demolition and renovation waste, as well as waste recycling and reuse (Cheng and Ma, 2013). A more comprehensive framework was further explored by Yeheyis et al. (2013) for maximizing the usage of reduce, reuse and recycle C&D waste strategies to achieve minimal environmental impacts over building's entire life cycle.

5. Discussion and Conclusion

BIM is gradually being extensively adopted by construction professionals and practitioners in the process of effectively enhancing the design, construction and operation level throughout a building's lifecycle (Arayici et al., 2011). As construction industry are being confronted with great challenges to improve green features such as productivity, efficiency, and profitability of construction projects, BIM is currently considered as a transformative information technology to achieve these goals. From the above review of existing green BIM research, several observations can be made. Firstly, the demand for developing a comprehensive green BIM tool for providing a Cradle-to-grave monitor in different phases of a building's life cycle is increasing. Secondly, the current trend of green BIM tool concentrates on the preliminary and early stage. The limitation of the research in the construction stage and later phases hinders the overall development of the application of the green BIM in the construction industry. Therefore, green BIM tool should provide a life-cycle assessment that comprises analysis and evaluation of the environmental impacts of building components and elements throughout the whole life cycle of a building from the originally inception to demolition (Wu et al., 2014)(Wu et al., 2014)(Wu et al., 2014)(Wu et al., 2014)(Wu et al., 2014)(Wu et al., 2014)(Wu et al., 2014). Third, lacking the available software in the green BIM make the application of green BIM a challenge in the practice of the green building. As indicated by Chong et al. (2017), there is a great need to enhance the interoperability among BIM software and energy simulation implements. Besides, it is urgent to build up and develop open-data standards in the domain of energy to suit the requirements of BIM software (Cemesova et al., 2015, Gourlis and Kovacic, 2017). However, it is believed that the potential of incorporating the green BIM tool into other software such as energy analysis will increase the overall efficiency of the analysis, which provides a further study area.

In addition, given the limitation that spare research has been investigated to promote the exertion of BIM for sustainable building performance assessment in the stage of maintenance, renovation, and demolition. The future research agenda has been outlined: 1) future application of BIM should resort to reduce, reuse and recycle strategies for sustainable purposes; 2) developing a more comprehensive and inclusive green building certification systems worldwide is demanding; 3) the system should streamline the process of integrating BIM into energy analysis software for more efficient management of low energy consumption and minimal carbon emissions; 4) more efforts should be exploited to develop a real-time monitoring and tracking technique for managing carbon emissions from construction activities in different stages.

Green BIM has been advocated for its benefit for initiating environmentally reliable and resource efficient building in a healthy built environment. Based on a comprehensive review of green BIM related issues, five main stages of a building's lifecycle are identified. The limitations of green BIM adoption are discussed, and future research directions are proposed. This research may establish a preliminary framework regarding the application of BIM-based tool for developing sustainable building process over building life cycles. Beneficial outcomes could be a stimulating indicator facilitating building construction practitioners implementing green BIM instrument for sustainable purposes.

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