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New Opportunities of Using Building Information Modelling (BIM) for Green Buildings

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Abstract

Building information modelling (BIM) is a collaborative working process using digital models to support virtual design and construction (VDC) which can streamline project delivery workflow and improve building performance. The use of BIM to provide data for energy performance evaluation and sustainability assessment is known as Green BIM. In recent years, BIM adoption has grown significantly in many countries and cities around the world. BIM-based energy analysis can help project design teams to examine and create optimized energy efficiency. A BIM-based approach to green building can assist professionals in predicting the outcomes of construction to minimize its impact on the environment throughout its life cycle. The Green BIM potentials can be enhanced when useful information and data are collected and provided to facilities managers and building end-users. This research paper will explain the key characteristics of BIM, describe the information requirements and management for sustainable built environment, and discuss the new opportunities of using BIM and other related technologies for promoting green buildings.

1. INTRODUCTION

Building information modelling (BIM) is a collaborative working process using digital models to support virtual design and construction (VDC) which can streamline project delivery workflow and improve business performances and productivity throughout the total life cycle of building assets (SMACNA, 2017; WEF, 2018). Nowadays, BIM has grown significantly in many countries and cities around the world and is considered a major driver for the digital transformation and innovation of the construction sector (Hui, 2018).

In recent years, a lot of research and literature have come up about the role of BIM in sustainable construction; the relevant publications on this subject registered an exponential growth (Santos, *et al*., 2019). It is believed that the "green dimension" in BIM has good potential to enhance environmental sustainability over building life cycles (Bonenberg and Wei, 2015; Wong and Zhou, 2015). In practice, the use of BIM to provide data for energy performance evaluation and sustainability assessment is known as Green BIM (Krygiel and Nies, 2008; Lu, *et al*., 2017; Maltese, *et al*., 2017). Figure 1 shows the basic concepts of Green BIM (ABRI, 2015). Usually, Green BIM includes building energy modelling dealing with project energy performance to identify options to optimize building energy efficiency during the life cycle. In addition, BIM can provide a decision support basis for evaluating the key carbon emission sources to achieve a holistic design and assessment of low carbon buildings (Gan, *et al*., 2018). A BIM-based approach to green building can assist professionals in predicting the outcomes of construction so as to minimize its impact on the environment throughout its life cycle.

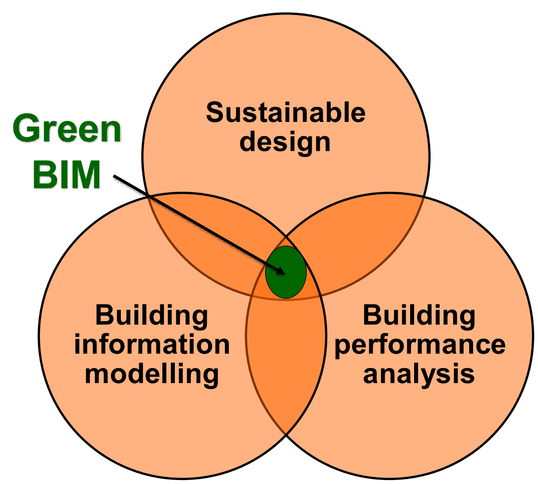

Figure 1. Basic concepts of Green BIM

To explore the Green BIM development, this research paper will explain the key characteristics of BIM, describe the information requirements and management for sustainable built environment, and discuss the new opportunities of using BIM and other related technologies for promoting green buildings. It is hoped that the Green

BIM potentials can be further developed and enhanced for environmental sustainability monitoring and management over the building life cycle.

2. KEY CHARACTERISTICS OF BIM

BIM can be defined as the process of creating and using digital models for design, construction, and/or operations of building or infrastructure projects (MHC, 2009). Such digital models are meant to simulate the construction project in a virtual environment and can be used for planning, design, construction, and operation of the facility. A building information model can be used for visualization, enhanced documentation, detection of conflict, interference and collision, building performance and structural analysis, code reviews, construction sequencing, prefabrication and automated assembly, cost estimating and facility management (Azhar, 2011). A BIM model is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle. Figure 2 shows the typical applications of BIM at different stages of the project life cycle.

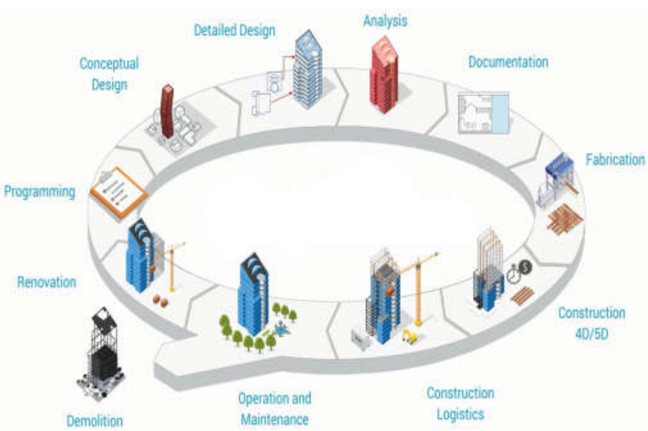

Figure 2. BIM at different stages of the project life cycle
(Source: http://blog.drawbotics.com/2018/11/07/the-bim-revolution-in-building-management/)

2.1 BIM as an enabling platform

BIM can act as an enabler of digital transformation in the built environment (Hui, 2018) and for gaining lean and green project outcomes (Ahuja, Sawhney and Arif, 2017). The technical core of BIM is the software tools that enable 3D modelling and information management. The main point of this technology is that it makes it easier to gather and share data. By establishing a common data environment (CDE) and a single source of information, BIM-supported projects allow the stakeholders to have effective access to every piece of information, in order to enhance collaboration & integration. For green building projects, to facilitate modelling and analysis, four BIM capabilities are often applied including MEP (mechanical, electrical and plumbing) system modelling, energy and environment analysis, constructability analysis and structural analysis (Ahuja, Sawhney and Arif, 2017).

BIM is an important element for the VDC process through which design and construction partners collaboratively simulate all work on a construction project in a 3D virtual environment before performing any work on-site, in the real world (SMACNA, 2017). Basically, VDC is the management of integrated multi-disciplinary performance models of design-construction projects, including the product (i.e., facilities), work processes and organization of the design-construction-operation team in order to support explicit and public business objectives. With the support of BIM solutions, VDC allows project members to work in a common language, where all necessary information is transparent and instantly available. By doing this, it is hoped that challenges can be solved proactively and cooperatively to increase efficiency, productivity and quality.

2.2 Collaboration

BIM is the process of creating a 3-D design platform that allows the architect and the engineering consultants to participate in the design process on a real-time, multidiscipline basis. One of the most valuable functions of BIM is its ability to improve the coordination between multiple design disciplines, thus reducing errors. It is believed that BIM can enable a data-driven approach to building planning, construction and maintenance (El-Diraby, Krijnen and Papagelis, 2017). When everything is connected through BIM for managing the interactions, it can improve project/issue management as well as design/construction coordination. To achieve effective collaboration and total integration, an alternative way of thinking and a different approach to project procurement and delivery are required. By using a BIM-based collaboration in an integrated design system, it can enhance design quality and productivity by utilizing necessary support for a collaborative design.

In real life, BIM can be adopted and implemented in numerous ways, but it is essentially a software-facilitated working process used by the stakeholders in the construction industry. The use of BIM models is an integrated process whereas designers and contractors can derive many functions from its use. As an integrated design and management tool used to enhance communication and collaboration among all the project stakeholders, BIM is changing the way architects, engineers, surveyors, contractors, building owners, facility managers and suppliers work together (Crotty, 2012). BIM allows the stakeholders to simultaneously share, amend and access the building's physical and functional information on a building project or facility, in order to simplify and efficiently coordinate the work. To ensure people can work together throughout a building's life cycle, it is important to engage the end-users and their keen interest in selecting green features (El-Diraby, Krijnen and Papagelis, 2017).

2.3 Visualization

BIM visualization helps streamline projects, inform decisions, and minimize challenges by bringing projects and components to life before they actually begin and are being constructed. Usually, in typical building projects, architectural visualization serves many critical functions to convey aesthetics, mass, function, and meaning of the conceptual or final design, in relation to the owner's requirements and intent for the new structure. When integrated with the time and schedule, BIM enables a 4D sequencing process that can help the project team discover potential schedule improvements and optimize construction operations.

Nowadays, the 3D BIM technology and advanced visualization techniques can work hand-in-hand to generate a complete picture and performance models for building energy analysis, daylighting simulation, construction planning and execution, as well as facilities maintenance and energy conservation. Computer graphics, photo-realistic images, animation, walk-/fly-through the models can be used to improve the understanding in different design, presentation and analysis tasks. Figure 3 shows an example of BIM-supported daylight visualization and analysis. In addition, a comprehensive BIM solar shading analysis can help determine building orientation or photovoltaic system location.

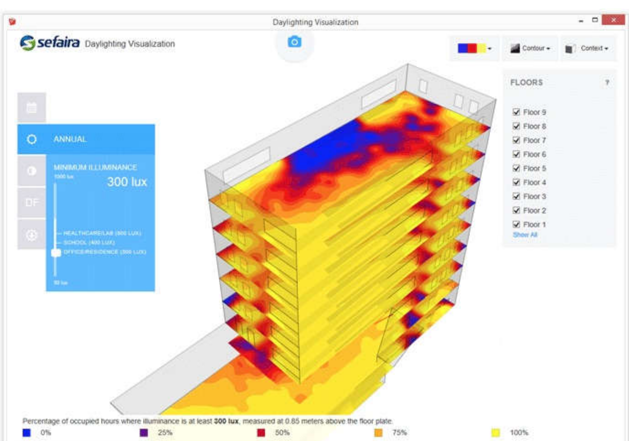

Figure 3. BIM-supported daylight visualization and analysis (Source: https://architosh.com/2015/10/energy-modeling-what-you-need-to-know-about-green-building-design-and-leed/)

BIM-based visualization can enhance visual representation and communication, acting as an effective collaboration tool. The realistic BIM model of the building can help the project team to stay on the same page and communicate crucial updates on a timely and straightforward manner when necessary. Furthermore, a well-constructed BIM model can allow construction managers to run a number of alternative scenarios in order to visualize the entire planned sequence of the project. This visual representation can subsequently be shared with the client and the other stakeholders and function as a basis for further action.

With more innovation of virtual prototyping and visualization technology, such as virtual reality (VR), augmented reality (AR), mixed reality (MR) and immersive visualization, it is expected that intelligent 3D-modelling and real-time BIM visualization can be applied more effectively to empower the BIM-based decision-making process. Recently, the new partnerships between BIM and visualization software vendors (such as Autodesk and Unity; Graphisoft and Twinmotion) has provided some hints on future visualization power for BIM applications. Moreover, at macro-level representation, the integration of BIM and geographical information system (GIS) can provide visualization and analysis of structures in the context of the natural and built environment (Wang, Pan and Luo, 2019).

2.4 Analysis

In the past, insufficient interoperability resulting from complex data exchange between architectural design and building energy simulation has prevented the efficient use of energy performance analyses in the early design and later stages (Kim, *et al*., 2015). In particular, the powerful building energy modelling (BEM) tools were not commonly and fully utilized in decision support analysis for engineering systems and sustainability evaluation (Kamel and Memari, 2019). At present, to resolve the interoperability and data exchange issues, a corrective middleware can be utilized to overcome the shortcomings in BIM-to-BEM interoperability process (BBIP). For instance, the middleware tool can modify a gbXML file prior to adoption in energy simulation. However, this conversion process is not always error-free and user-friendly.

In order to use BIM effectively for building energy modelling and analysis during the design process, the BIM-BEM process and related technology integration must be addressed carefully (Farzaneh, Monfet and Forgues, 2019). To streamline the BIM-BEM integration process, it is recommended to embed the technological approaches within the whole design process by using a proper level of development (LOD) (Jin, *et al*., 2019) and information requirements via model view definition (MVD). The current data exchange formats or data schema commonly used in BIM, such as Industry Foundation Classes (IFC), Green Building XML (gbXML), should be refined and enhanced to satisfy the information management.

3. GREEN BUILDING ISSUES

Green building design is not merely the use of energy-efficient materials and equipment. It also involves the creation of products and systems with a light footprint on the environment over the full building life cycle. As such, sustainable building design should be thought of as a process, not just a goal. It should allow for a broader evaluation and assessment of the environmental issues, economical and societal impacts of the building planning, construction and maintenance.

3.1 Green building assessment

The various benefits of BIM such as effective decision making, improved analysis, easier access to information and simpler green building assessment provide an optimized solution for sustainable design and construction (Ilhan and Yaman, 2016). With an integrated BIM-based design process, the necessary data for green building assessment can be extracted from BIM models for calculating the green rating and providing feedback for further evaluation. Also, the essential documentation necessary for obtaining green building certification can be generated timely and efficiently. In some situations, a BIM-based approach can provide an automatic assessment and evaluation of building envelope design for thermal performance based on overall thermal transfer value (OTTV) calculations (Natephra, Yabuki and Fukuda, 2018).

Generally speaking, BIM has the potential to aid designers to select the right type of materials during the early design stage and to make vital decisions that have great impacts on the life cycle of sustainable buildings (Jalaei and Jrade, 2015). When linked with green building rating systems (such as LEED and Green Mark), BIM can help automate the process of identifying the required number of points based on the selected certification categories, accumulates the total selected credits/points as well as suggests the qualified certification type within BIM platform (Jalaei and Jrade, 2015; Liu, *et al*., 2017). This will facilitate the integration of BIM and sustainability assessment.

3.2 Building performance analysis

BIM can improve not only the construction process but also enable exploration of alternative approaches for decision support (Habibi, 2017). It can help facilitate review of results and methods for improving building performance in terms of energy efficiency and indoor environmental quality. One example is the use of BIM for building performance simulations and daylighting analysis (Kota, *et al*., 2014) which often helps building designers to quickly evaluate the design options. Another example is multicomponent energy assessment of houses and apartment buildings using BIM-based parametric studies to identify critical variables and optimize the design parameters (Singh and Sadhu, 2019).

By integrating BIM with building simulation tools and optimization methods, it is possible to achieve building performance optimization and support the visualization and management of a building's operational performance (Gerrish, *et al*., 2017). When handling the production and sourcing of a large amount of data for the performance analysis, the parametric modelling tools such as Dynamo can be used to extract basic building geometry and performance related information from the BIM environment and convert them into suitable data-interchange format for building simulation and optimization tools. This can greatly increase the capability of the BIM-based performance analysis and optimization.

3.3 Sustainable building design process

To achieve sustainable design a responsive design process able to assess and optimize the use of a variety of available processes, systems, techniques and materials options is required (Ahmad, Aibinu and Thaheem, 2017). It is believed that BIM as a design iterative tool can offer new insights into the sustainable building design process in a multi-dimensional manner by considering the following three important sustainability dimensions (Santos, *et al*., 2019).

(a) Economic: Rapid cost feedback and evaluation.
(b) Environmental: BIM enabled life cycle impact analysis (LCIA), life cycle assessment (LCA), and other green building rating systems.
(c) Social: BIM-based quality checking process.

Not only building projects, Green BIM can also be applied in sustainable infrastructures and planning site location (Bonenberg and Wei, 2015). In principle, sustainable design refers to the entire life cycle of the building or infrastructure, which includes maximizing the conservation of resources (energy, water, land and materials), protecting the environment, reducing pollution, providing people with healthy, comfortable and efficient use of space, and establishing a harmony of nature and built environment. By using BIM it is possible to reduce waste and improve construction quality. BIM provides the simulation and analysis of scientific collaboration platforms for designers, architects, utilities engineers, developers and even end users. It helps them to take advantage of 3-D digital models in design and construction of projects and operational management.

3.4 Environmental impacts and low carbon building

By linking BIM to sustainability analysis, it is possible to evaluate environmental impacts more effectively over the entire lifespan of building or infrastructure. The typical building project life cycle phases include planning and design, construction, commissioning, operation and maintenance, refurbishment and demolition (end of life). It is believed that BIM has the potential to be applied in each of these phases for promoting sustainable construction (Chong, Lee and Wang, 2017; Santos, *et al*., 2019).

On the other hand, BIM provides detailed physical and functional characteristics of buildings that can be integrated with various environmental modelling approaches to achieve a holistic design and assessment of sustainable low carbon buildings (Gan, *et al*., 2018). BIM provides a decision support basis for evaluating the key carbon emission sources throughout a building's life cycle and exploring more environmentally sustainable measures to improve the built environment. For instance, the embodied and operational carbon quantification and analysis can be performed using a BIM-based methodology framework.

4. GREEN BIM POTENTIALS

Many people believe that the future map of BIM technology should focus on how to use the BIM data/information to enhance efficiency/effectiveness through the following developments: BIM Model >> Integration >> Automation >> Optimization. When applied to Green BIM, this is still valid (as briefly explained in the previous sections) and can set out the strategies and future directions for successful sustainable design with BIM (Krygiel and Nies, 2008).

The nexus between BIM and green buildings can be described by the Green BIM Triangle which consists of three aspects (Lu, et al., 2017).

(a) Project Phases: BIM in supporting the design, construction, operation, and retrofitting processes of green buildings.
(b) Green Attributes: the various functions of BIM for green building analyses such as energy, emissions, and ventilation analysis.
(c) BIM Attributes: such as BIM in supporting green building assessments.

Table 1 Green BIM potentials throughout the lifecycles of green projects [adapted from Lu, *et al*.(2017)]

1. Design Phase: Facilitate data exchange and integration, provide visualized building performance analysis and simulations, assess design alternatives.
2. Construction Phase: Analyze various environmental impacts of construction process, contribute to waste reduction, improve construction productivity and performance.
3. Operation Phase: Help to monitor the sustainability performance of buildings.
4. Renovations and retrofit: Support the retrieving of energy and capital investments, benefit energy and waste management.

Table 1 summarizes the potentials of Green BIM throughout the life cycles of green projects. It can be seen that many of these potentials have not been fully developed and utilized at the present moment, especially in the construction, operation and renovation phases. It is believed that the main BIM functions for sustainability analyses include energy consumption, carbon emissions, natural ventilation, solar and lighting analysis, acoustics, and water usage. But there is a lack of clear industry standards or codes for the various aspects of Green BIM applications.

4.1 Automation of green building assessment

BIM-supported green building assessment (GBA) has attracted much attention in different countries because of the growing importance of green building rating systems (Ansah, *et al*., 2019; Solla, *et al*., 2019). By integrating GBA schemes with BIM, people can utilize BIM data to evaluate and obtain green building credits in order to facilitates the assessment process. There is a trend in many countries to develop full integration and automation of the GBA so as to enhance the application of BIM in the green building certification. It is also possible to integrate BIM and Web Map Service (WMS) technologies for site location and transportation analysis (Chen and Nguyen, 2016). The automation of GBA process can help optimize building sustainability assessment using BIM and greatly simplify the GBA process and certification (Carvalho, Bragança and Mateus, 2019).

4.2 Building design optimization

A BIM based building design optimization method can facilitate designers to optimize their designs and improve buildings' sustainability (Liu, Meng and Tam, 2015). The Green BIM system can be configured to help designers search for the tradeoff between life cycle costs (LCC) and life cycle carbon emissions (LCCE) of building designs. BIM can also be integrated with Genetic Algorithm Optimization and Monte-Carlo Simulation to implement a stochastic LCC model for building to select the optimum building materials alternatives (Marzouk, Azab and Metawie, 2018). In addition, BIM-centric design and analysis software can be used to model and optimize building integrated photovoltaics (BIPV) systems (Kuo, et al., 2016; Gui, et al., 2018).

Wong and Zhou (2015) found that most Green BIM research today focused on environmental performance at the design and construction stages of building life cycles. Few studies concentrated on the development of BIM-based tools for managing environmental performance during the building maintenance, retrofitting, and demolition stages. It is believed that sustainability analysis for both new development and retrofitting projects are important for effective low-carbon management in the society (Chong, Lee and Wang; Khaddaj and Srour, 2016). To maximize the environmental performance, the BIM system should offer better integration with facility operation maintenance manuals and the use of cloud-based BIM technology to enable the management of building sustainability using big data is also needed.

4.3 BIM and LCA integration

Life cycle assessment (LCA) methods are often used to evaluate environmental impacts of building materials (such as during the manufacturing and operation phases) and support the evaluation of environmental improvement potentials in building construction (Najjar, *et al*., 2017; Röck, *et al*., 2018). The integration of BIM and LCA to validate the development of design concepts can provide an optimal procedure for achieving sustainable building and empowering the decision-making process in the construction sector. The BIM-integrated approach enables identification of design specific hotspots which can be visualized on the building model for communication of LCA results and visual design guidance (Röck, *et al*., 2018).

In general, BIM provides a platform to incorporate sustainability information in the design of buildings, however, interoperability of BIM with LCA tools needs further investigation (Nizam, Zhang and Tian, 2018). For example, the BIM environment, data analysis tools, embodied energy estimation, LCA databases and results must be planned and linked effectively. To streamline the assessment, it is important to ensure BIM-LCA interoperability and enable an automated or semi-automated process (Shadram, *et al*., 2016). It is also essential to provide a convenient linkage between the BIM model and external databases to provide a seamless analysis (Zhang, Nizam and Tian, 2018). If integrated efficiently, BIM can contribute to simplifying data input, and optimize output data and results during the LCA application in the sustainable design process (Soust-Verdaguer, Llatas and García-Martínez, 2017).

5. DISCUSSIONS

At present, the lack of suitable computer tools and the complications of the BIM models are hindering the adoption of Green BIM. The main challenges and research gaps have been identified by some researchers (Lu, *et al*., 2017; Santos, *et al*., 2019a) and are summarized as follows.

(a) Interoperability problems between BIM tools and sustainability tools
(b) Limited capability of BIM supporting the construction and operation phases of green projects
(c) Lack of clear industry standards or codes for the various aspects of Green BIM applications
(d) Lack of appropriate project delivery methods to leverage Green BIM applications
(e) Lack of incentives and low industrial acceptance for the adoption of Green BIM

The exchange of information between BIM and other tools is a critical factor affecting the integration of BIM and green buildings (Andriamamonjy, Saelens and Klein, 2019). It is believed that an efficient interoperability along the life cycle supported by BIM will allow an overall better management and help users to improve sustainability of projects (Muller, *et al*., 2019). This interoperability must consider not only data, but also should be concerned with broader aspects, such as processes and guidelines, avoiding information loss and facilitating analysis. For instance, BIM-based energy analysis can be applied to post-occupancy evaluation, retro-commissioning, continuous commissioning, and retrofit of existing buildings for providing reliable building energy performance modelling (Ham and Golparvar-Fard, 2015; Khaddaj and Srour, 2016; Motawa and Carter, 2013). Whole-life cycle energy assessment can be incorporated into BIM for refurbishment projects (Edwards, *et al*., 2019). In addition, BIM can facilitate off-site manufacturing for buildings to enhance sustainability and cost effectiveness (Abanda, Tah and Cheung, 2017; Yin, *et al*., 2019).

To enhance the integration, the information requirements of green building issues must be considered carefully, especially during the construction, operation and renovation phases (Chong, Lee and Wang, 2017). Usually the environmental properties such as suppliers' Environmental Product Declarations (EPDs) should be included in the BIM objects, in a properly standardized format structured according to the project's level of development (LOD) (Jin *et al*., 2019; Shadram *et al*., 2016). This can ensure sharing consistency, automated data exchange and accurate building information throughout the building's or facility's life cycle. More efforts are needed to be put in collecting, analyzing and sharing the right data for Green BIM applications. For example, reliable data exchange protocol and standard of building information is needed for BIM-enabled operations and maintenance work processes (Hitchcock, *et al*., 2017).

6. CONCLUSIONS

Up to now, BIM is still not commonly and effectively oriented to green and sustainable building, but it has great potential being able to support and enhance the analysis, monitoring, management and optimization of environmental sustainability over a building's full life cycle. The Green BIM potentials can be enhanced if useful information and data are collected and provided to facilities managers and building end-users. When BIM model is fully integrated with green building design and analysis, it can facilitate automation of green building assessment, optimization and monitoring of building performance, and evaluation of life cycle environmental impacts.

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