Comprehensive Evaluation of Different Aspects of BIM Applications in Sustainable Design

Mohammad Ahmadzadeh Razkenari, SeyedHessamoddin Moussavi Nanekhara and Khalegh Baratia

1. Civil and Environmental Department, Sharif University of Technology, Tehran 2566826585, Iran
2. Civil and Environmental Department, Iran University of Science and Technology, Tehran 2565845637, Iran
3. Civil and Environmental Department, The University of Isfahan, Isfahan 8642597426, Iran

Abstract: Growing environmental concerns require efforts for application of sustainability in construction industry. Today, there is an increasing need for sustainable building design. Besides, BIM (building information modeling) is one of the most noteworthy developments in construction industry. BIM is used to make the planning, design, construction, and operation process more integrated. The purpose of this paper is to survey application of BIM in sustainable building design. This exploration is done by reviewing the existing studies in the field of BIM and sustainable design. There have been few attempts to evaluate and analyze the benefits of BIM in sustainable design, and existing researches have not developed integrated analysis to evaluate different aspects of BIM application. In this study, BIM and sustainable design researches are categorized into some major areas. First, frameworks and design strategies for better implementation of sustainable design have been developed. Other application of BIM software is for improving sustainable design in which some case studies have been presented for this purpose. Another major area is focusing on a specific aspect of sustainable buildings such as using natural resources, energy simulation, daylighting analysis and carbon emissions. Scrutiny review of the current studies shows excellent potential for interaction of BIM with sustainable construction.

Key words: BIM (building information modeling), sustainable design, green buildings, sustainable development, built environment.

1. Introduction

The concept of sustainability is based on the interrelations between human societies and the natural environment. Sustainable development was first proposed by the Brundtland Commission in 1972 as meeting the needs of the present without compromising the ability of the future generations to meet their own needs [1]. Kibert in 1994 defined the concept of sustainable construction as the creation and responsible management of a healthy built environment based on resource efficient and ecological principles [2]. The provision of buildings that use less primary material and energy, and produce less pollution and waste is common interpretation of sustainability in the construction industry. The terms of high performance building, green building, and sustainable construction are often used interchangeably. Throughout the life cycle of the construction, maintenance, and destruction of a building, the building produces environmental pollution due to consumption of energy and resources, emission of pollutants, and discharge of wastes. Based on the current researches, worldwide, buildings account for 33% of all energy consumption, 40% of all resource consumption, 50% of CO2 emissions, and 20%~30% of waste discharged [3].

The goal of sustainable design is to produce green buildings, which are defined by the USGBC (US Green Building Council) as environmentally responsible, profitable and healthy places to live and work. Advancing sustainable design with 2% increase in design costs, on average, results in life cycle savings of approximately 20% of total construction costs which is more than ten times the initial investment. Building design and construction leads to series of decision-makings about energy and resources.
Designers often develop conceptual designs, including building shape and appearance, without considering energy and resource consumptions. Furthermore, there is no direct link between energy simulation and design models causing difficulties in tracing the effects of changes. Linking new approaches to simulating and analyzing considering sustainable design to enhanced coordination of information via BIM (building information modeling) throughout the construction process allows both reduction of rework and waste and the realization of “designed-for-performance” new buildings and infrastructure through dialogic engagement of stakeholders. The literature regarding the integration of sustainability tools with BIM has shown that even though there are few researches and efforts to use BIM tools for sustainable design and assessment, these tools have considerable capability not only to make building design more sustainable but also to easy access to information in every phase in project life cycle. In conceptual design stage, managers have to make decisions regarding sustainable design strategies. Using BIM as an integrated process helps designers, contractors and owners to see how the project will perform and it leads to making better decisions.

This study aims to provide a comprehensive review on different aspects of BIM application in sustainable building design. According to existing efforts, there is a hypothesis that using BIM tools can improve building sustainable design. However, BIM and sustainable design relations have not investigated thoroughly yet to make this application obvious and manageable. The aim of this research is to investigate the contribution of BIM in sustainable design. Firstly, BIM tools are identified and their performance and applications are discussed. Then, benefits and limitations of using these tools in sustainable design are explored. The research methodology includes a comprehensive literature review to identify BIM tools and their applications in project life cycle. Then considering the interrelation between BIM and sustainable design, a classification for different aspects of BIM application in sustainable building design is presented. This classification helps to make better understanding of benefits and limitations of using BIM as a tool for sustainable design.

2. Literature Review

2.1 Building Information Modeling

BIM 4D models emerged by adding time dimension to 3D CAD models (including three dimensions: place, size and shape). Fourth dimension promotes full construction coordination in design. Subsequently, cost dimension was added to 4D format that brought BIM to new improved 5D level. Fifth dimension leads to the calculation of cost for the entire construction project as well as for project parts. The last development of BIM brought it to the new 6D level. The sixth dimension is about the life cycle of building, management of its facilities, and an environmental impact. Linking sixth dimension with other five dimensions is currently difficult using the software tools available on the market. Fig. 1 shows five steps to getting start with BIM.

Dealing with complexity of achieving sustainability and energy efficiency in building design due to multidisciplinary interdependencies, BIM is an innovative solution since it allows for multi-disciplinary information to be covered within one model [4]. BIM is an innovative methodology for designing the entire building and storing related information in an integrated database. BIM is defined as a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building’s life cycle. BIM provides construction stakeholders an opportunity to simulate the entire process of their construction projects in a virtual reality environment.
2.2 Sustainable Building Design

In this research, sustainable building design is defined as the intention to reduce or eliminate negative impacts on society and environment in building designs and improve the building performance at the same time. From the first generations, sustainability was used in building design. Making the most effective use of natural resources, specifically natural daylighting and ventilation systems, was the main intention of the designers. In the early 20\textsuperscript{th} century, industrial development and growing trend into using natural resources in construction industry raised more concern about future development. Sustainable building design is an answer to this concern, in building environment. Main areas in sustainable design are shown in Fig. 2. Usually, sustainability assessment tools are used to execute and evaluate sustainability in design, and construction stages of projects.

2.3 Sustainability Assessment Systems

Recently, many building assessment systems have been developed to certify and rate the performance of green buildings. These assessment systems can simply evaluate building design approaches and construction processes from sustainability viewpoint. In fact, building assessment systems generally offer a label or plaque indicating the building’s rating, and a plaque on the building awarded as a result of achieving green building certification is a public statement of the building’s performance [5, 6]. The revolutionary approach of building assessment systems was proposed 1989 in the United Kingdom with the advent of a building assessment system known as BREEAM (building research establishment environmental assessment method). BREEAM was both a standard system for sustainable design in buildings and an assessment system for evaluating their performance. Afterward, similar systems were developed in many countries as an accepted approach to green construction. In the United States, LEED (leadership in energy and environmental design) was launched as a fully tested rating system in 2000 by the USGBC. For other pioneer systems in this field, we can address CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan (2004); Green Star in Australia (2006); DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) in Germany.
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1. Building Assessment Systems

Building assessment systems can use a single number to describe the building’s overall performance (e.g., LEED) in which the system should convert the different units describing the building’s resource and environmental impacts and conditions resulting from the building into a series of numbers that can be added together to produce a single overall score. Otherwise, a building assessment system may depict the building’s performance in major areas, such as environmental loadings or energy and water consumption, compared to conventional construction, using an array of numbers or graphs (e.g., the sustainable building tool). Although the second approach yields more detailed information, its complexity makes it difficult to compare buildings, depending on the range of factors considered.

2. BIM in Sustainable Design

Although BIM has this capability to support sustainable design approach and facilitate its application, the use of BIM for building energy analysis and simulation applications was mentioned in only a few research papers and some BIM-based tools and systems have been investigated to execute sustainability in design and construction. Accordingly, BIM can assist sustainable design in the fields of building orientation, building massing, day-lighting analysis, water harvesting, energy modeling, sustainable materials, site and logistics [8]. As shown in Fig. 3, the applications of BIM tools in sustainable design were classified into five main areas.

3.1. Natural Resources

One of the major areas of sustainability is making use of natural resources. By a much deeper integration of ecosystem within buildings, energy usage can be reduced, and consequently, the sustainability rating of the design will be improved. In order to increase this integration, there should be enormous attention to the...
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Fig. 3 Main research areas of BIM applications in sustainable design.

Table 1 Software and strategies for each step in Wong and Fan research [4].

<table>
<thead>
<tr>
<th>Step 1: Inherent BIM features</th>
<th>Step 2: BIM-based analysis tools</th>
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<tbody>
<tr>
<td>Software</td>
<td></td>
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<tr>
<td>Revit, ArchiCAD, Bentley, Graphisoft, TriForma (Beta), etc.</td>
<td>Ecotect, IES-VE, GBS (Green Building Studio), EnergyPlus, TRACE700, eQUEST, etc.</td>
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Green strategies
- Building orientation;
- building massing;
- load data, etc.

Building load calculations;
- energy analysis;
- lighting design;
- ventilation;
- materials, etc.

environmental conditions of the surrounding area and physical orientation and geometry of the building. Making best decision on building orientation, building massing and day-lighting is possible by using BIM analysis tools. Now, BIM analysis for building geometry needs re-creating the building geometry in several new applications until reaching the best responses. The primary and most obvious need to achieve better sustainable solutions with BIM is better interoperability between software packages to reduce these reworks and move forward to analysis packages for building geometry [6, 8]. Another aspect of making use of natural resources is recognition and utilizing renewable energy sources. The ability to use the most common renewable energy sources is directly dependent on the climate and the place. There are seven recognized renewable energy sources including solar, wind, biomass, hydrogen, geothermal, ocean and hydropower. For energy efficient buildings, with possible free energy, supplying the energy needs with renewable energy is the next sustainable step [8].

3.2 Integrated Project Delivery

Wong and Fan [4] in their studies demonstrated the contribution of BIM to sustainable building design from the two perspectives of IPD (integrated project delivery) and design optimization. An integrated design model would allow for structural analysis, building performance analysis, MEP (mechanical, electrical and plumbing), material usage analysis, GIS, etc. Integrated project delivery with BIM can reduce the risks and the duration of a project, which subsequently reduces costs and improves the project quality and lifecycle performance (Autodesk 2008).
Wong and Fan [4] proposed two steps for design optimization. First step is the creation of basic models using the appropriate inherent BIM software; second step is to export these models to BIM-based analysis tools as appropriate. Software and strategies for each step are demonstrated in Table 1.

In sustainable viewpoint, there is a critical need to integrate all the building systems within themselves as well as external systems. Using three-dimensional virtual models, structural and mechanical models can interact with architectural models, and shape full system coordination. Therefore, true integration in all aspects of building design and construction becomes more real and compelling. Even so, currently, BIM rarely contains properties to track energy, water, and light efficiencies in operation phase or development of fully integrated project life cycle assessment tools [9].

Surveys of the various BIM software systems and models for integrated analysis of building performance or for complex processes of sustainable design, have been proposed in many research papers and books [10, 11]. A single integrated model for capturing and coordinating information and discussed of its benefits was proposed. A conceptual BIM-based model was introduced to improve the evaluation process and meet the industry requirements for sustainable buildings. Some researches provided an introduction to the sustainable design progress and its connection with BIM analysis tools to assess building performance and developed case studies to evaluate BIM performance in sustainable construction industry [12, 13].

3.3 Frameworks and Standards

Another major area of researches related to the application of BIM in sustainable design is focused on the development of green building standards and frameworks. Detailed review was presented on the existing literature surrounding frameworks and methodologies to evaluate the benefits of BIM and sustainable design. A conceptual framework was developed to illustrate the use of BIM for sustainability analyses throughout the project life-cycle. A sustainable framework and the best practices guide were proposed to explore the functions of BIM that facilitates sustainable design principles.

3.4 Energy Performance

BIM is also being used to evaluate the energy performance of buildings in some researches. Researches in energy simulation using BIM software are more diverse and more popular [3, 14-19]. Some studies emphasize on design technology using BIM tools, which can be used to conduct accurate daylight analysis along with energy simulation in building systems [20]. Ecotect, 3ds Max Design and Daysim are some software, which can be used for daylight design and analysis and was used in related case studies [7, 21-23]. Suitability of three building performance analysis software namely Ecotect™, GBS (Green Building Studio™) and Virtual Environment™, was evaluated for BIM-based sustainability analysis. Other papers proposed an integrated method that links BIM, energy analysis and cost estimating tools within green building certification system [24, 25]. A methodology was proposed for automated product model for climate-based daylighting simulation. ThermalOpt was developed as an MDO (multidisciplinary optimization) methodology for BIM-based passive thermal design of buildings and energy and daylighting simulation.

NZEB (net zero energy building) is a new term for green or high-performance buildings. In general, these are grid-connected buildings that export excess energy produced during the day and import energy in the evenings, such that there is an energy balance over the course of the year. In addition, energy requirements are presented from low-cost, locally available, nonpolluting, renewable sources [26-30]. Finally, NZE (Net zero energy) can come along with net zero water, net zero carbon emission and nontoxic. Some papers review potential challenges and opportunities for integrating optimization tools in net zero energy buildings design [31, 32].
3.5 Carbon Footprint

Although, building’s carbon footprint is currently a major component for measuring sustainability, there is no integrated software solution to track the carbon output as the project is being designed. Integration of carbon accounting by using BIM techniques has been discussed in few research papers and is an innovative research area [33]. Drexel University proposed “The Intelligent Buildings” course in which the idea to integrate the carbon accounting by BIM capabilities has been assessed in a course project. This course helps the students to learn how to calculate carbon footprints through the integration of multidisciplinary BIM and LCA (life-cycle assessment) tools [34].

4. Conclusions

Improving building performance is crucial for sustainable development, particularly to satisfy its environmental objectives. In the early design and preconstruction stages, the designers have to choose the most sustainable design from different design options. Making this decision needs clear and reliable details about estimated performance of the building. Thus, BIM can improve the design estimation using multi-disciplinary information covered in one model. BIM can present sustainability measures and performance analysis from early design stages. It will facilitate the very complex processes of sustainable design while capturing and coordinating information into a single integrated model. BIM can help designers to reduce resource consumption, increase on-site renewable opportunities, build consensus, review investment-grade audits, increase investor confidence, improve employee morale, and meet requirements for sustainable design and energy efficiency. It can also advance change management, enhance coordination and integration, and simplify information reuse. In this study, a comprehensive review has been conducted in application of BIM in building sustainable design. The review shows that BIM needs to further development in order to be applicable in the construction industry. Still, BIM has wide contributions in sustainable design.

There are some ongoing research activities to enhance application of BIM in sustainable building design. These research activities have been precisely classified into five main areas including relying on natural resources, improving integrated project delivery, developing practical frameworks and standards, considering energy performance, and calculating carbon footprint. Future developments related to this area are lying in two main categories. First, BIM is not satisfactory in the construction industry and mostly prefer using traditional trends. Changing the industry culture to make it more provided for using BIM in the design and construction can be next step. This goal can be achieved through professional development and government initiatives. Second, lack of well-educated and trained BIM professionals is a serious obstacle in BIM application. Hereafter, promoting educational program and case studies for the increasing general knowledge about BIM in industry expert can be considered.

References

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