BIM Approach for Sustainable Design of Flat Slab Buildings: A Review

Lovnesh Kumar Goyal¹, Hardeep Singh Rai²

¹Research Scholar, Civil Engineering Department, IK Gujral Punjab Technical University, Kapurthala, Punjab, India, 144603
²Civil Engineering Department, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India, 141006

Corresponding author’s e-mail address: lovnesh@gmail.com

Abstract. Building Information System (BIM) is a potential digital tool with the Architecture, Engineering, and Construction (AEC) industry that is used to represent the projects in three-dimensional models. It provides a central unified database that can be queried, filtered, manipulated and/or changed for analysis, thus providing a collaborative tool for all the stakeholders in the project throughout the life cycle of the project. Positive returns on investments are acceded by the contractors adopting BIM while it helps detect clashes of intersecting building components early in the design stages. BIM is proving of utmost importance while focusing on the development of sustainable buildings and to develop the cities smarter and intelligent. Environmental concerns warrant more and more sustainable buildings to be designed and implemented. BIM has an intrinsic role to play in building design to address the growing environmental concerns such as to reduce carbon footprint, to cut construction and demolition waste, selection of green material, quality of the indoor environment, water conservation, and health factors of inhabitants, etc. In the current practices, the simulation and environmental performance analysis follow the design phase of the project, thus not getting incorporated into the decision making at this stage. Some models of flat slab buildings are generated by some studies where required parameters were assigned to different elements of the building. This paper makes an effort to review the literature regarding the BIM approach to sustainable construction of buildings considering the flat slab models.

1. Introduction

Engineering and technology play a central role in human progress by tackling the urban challenges like energy, transportation, and climate change, disaster management, environmental concerns, natural resource management and sustainable building constructions [1]. It is a known fact now that the building industry has caused a noteworthy impact on the environment. The built assets are largely responsible for a high percentage of total greenhouse gases (GHGs), being the consumer and embodiment of the largest fraction of energy [2]. There is a demand for sustainable buildings with minimal environmental issues. The decisions related to energy and environmental concerns are most influential in the beginning stages of design and preconstruction [3]. The demand for sustainable buildings meeting ecological concerns like climate, culture, place, type, and resource consumption is increasing [4]. The design for sustainable, low carbon economy and more resilient building infrastructure is beset with a lot of hurdles [5]. These requirements are multi-faceted and often conflicting, uncertain, and lasting the whole
lifecycle of the project, thus requiring a paradigm shift to engage them fully. BIM, with its long-term process, view promises, and appropriate context for meeting these challenges [6]. BIM can address the growing environmental concerns by performing complex building performance analyses [7]. Plausibly, BIM, and sustainable buildings are the two most important trends today in the construction industry [8].

2. Methodology
The authors have followed the guidelines of writing a narrative literature review as the main motive of this review article was to bring into perspective the current and future issues regarding the BIM approach for sustainable design of flat slab buildings. Hence, there is no critique for the narrative overview for each paper reviewed. The following describes how the present outlining of the review was prepared for the readers. The two main sources of electronic research databases, namely Science Direct and Google Scholar, were used in addition to the ASCE Library. Reputed academic publishers were searched for articles to be reviewed. As the key concepts of the research, three main groups of the keywords were formulated to conduct the normal as well as advanced search online. The first group contained the keywords BIM and its related variants like 'Building Information Modeling,' 'BIM Process,' 'BIM tools,' 'BIM' etc. The keywords for the second group connoted the theme of 'BIM and Sustainability,' 'Sustainability, Sustainable building design,' 'Sustainable Building Construction,' 'BIM + Sustainability' etc. The third group of keywords was based on the concept of flat slab-like 'Flat Slab,' 'Sustainability in Flat Slab Buildings,' 'BIM + Flat Slabs,' 'Flat Slab digital design' etc. Figure 1 shows the diagrammatic scheme of the search methodology adopted. The collected articles were subjected to selection criteria, and the publication time spectrum was restricted to be between 2012 and 2020.

3. Building Information Modeling (BIM): An Overview
The concept of BIM was first used by Eastman in 1975 when it was conceived as "Building Description System" [9]. Computer-Aided Design (CAD) has been in vogue for drafting two dimensional (2D) drawings since the 1980s, and it has been practiced for three dimensional (3D) drawings for the last two decades [10]. Civil engineering has a new, increasingly important tool in BIM for design, construction, and operation/maintenance stages of the building process. BIM is fundamentally a co-ordinated and consistent data storage of advanced or simple information and knowledge generation procedures [11]. BIM allows the stakeholders in any building project to collaborate and model the building asset into a computer model even before the actual building comes into existence [12]. As a result of this modeling, any conflicts can be detected and remedied at this stage at the cost that is just a fraction of what it would have value to correct the real thing in the field. The cost-effectiveness is thus the main reason that many governments in the world are mandating the use of BIM in construction activities for their approval [13]. Building Information System (BIM) is a potential digital tool with the Architecture, Engineering, and Construction (AEC) industry that is used to represent the projects in three-dimensional models [14]. It provides a central unified database that can be queried, filtered, manipulated and/or changed for analysis,
thus providing a collaborative tool for all the stakeholders in the project throughout the life cycle of the project [15]. BIM enables the users to collaborate, simulate, and visualize all the information about a facility that may be geometric or non-geometric. However, BIM came to limelight only when the Autodesk promoted BIM commercially for creating a facility having physical and functional information [16]. All the stakeholders in the building project, e.g., the owners, architects, consultants, engineers, contractors, subcontractors, managers, etc. can collaborate amongst themselves right from concept planning, designing, construction, facility management to demolition. However, the participation of the building component manufacturers is hindered by the lack of dynamic links between their product catalogs and the BIM model [17]. Positive returns on investments are acceded by the contractors adopting BIM while it helps detect clashes of intersecting building components early in the design stages [18].

Consequently, BIM results in lesser requests for information (RFI) and a minimum of change orders (COs). BIM is becoming a vital tool in the drive on developing sustainable buildings, smart and intelligent cities. BIM is widely observed as 'disruptive,' 'revolutionary,' a 'catalyst' in the civil construction arena for innovation, efficiency, and productivity. BIM is expected to cause more sustainable construction activities that will help the developing countries alleviating their misery [19]. Though BIM has been well implemented in building constructions, the infrastructure projects have yet to harness the benefits of BIM [20].

4. BIM as an Enabler of Sustainable Design

Sustainability is considering and maintaining the equilibrium between the ecological, economic, and social indicators concurrently while managing the construction projects [21]. Sustainable built assets provide the best usability for owners over time and can meet the demands of the owners, building managers, and society at large [22]. The clients and designers are always concerned about energy consumption and efficiency with a sustainable construction project [23]. The case study by [24] shows that better decision making and substantial savings could be realized if the sustainability appraisal is done at the design stage, particularly in cases where it may be difficult or impossible to retrace the design decisions. The role of all stakeholders in the decision making is important as altogether different conceptions of the energy planning procedures are to be considered for the truly best usage of sustainable energy, along with the necessary policy measures [25].

BIM finds a crucial role to consider sustainability in the design areas that include building orientation, form, and envelope, building energy modeling, material selection, site and logistics management, water usage, etc. [26]. Over the last decade, the recognition of the role BIM plays in delivering sustainable projects to improve efficiency has become a priority [27]. BIM, with its tools and valuable high functions, develops the delivery process of the construction project from beginning to completion through sustainable purchase systems [28]. The salient points are depicted in Figure 2. BIM models can be collaborated and exported to various daylight and energy analysis tools. The BIM application software Revit Architecture can export the model to daylight analysis tools like Ecotect and 3d Studio Max Design. With the rising popularity and use of BIM in construction activities, the seamless integration of daylight analysis into the design process is becoming more pervasive and convenient [29]. The selection of building materials from a wide range of options has grown complex and difficult since the last decades. Apart from the basic cost, new aspects as regards sustainable development like increasing energy efficiency, local and recyclable material selection have to be incorporated in the decision making criteria. [30] propose a BIM environment framework that provides the most coveted and optimal combination for the building components, considering sustainability aspects, with negligible human intervention in the selection process. The goals of sustainable development are in actual bound by very interconnected dynamics involving a myriad of energetic, environmental, social, and economic dimensions [31]. The design lifecycle is a crucial tool to perform a detailed analysis of the sustainability of a building asset [32]. [33] aim to study the integration of BIM and sustainability practices in the construction projects to search for the critical success factors (CSFs) that can help it expand further. They focus their research on construction projects using BIM and similar smart
technologies for the sustainability of the project. [34] provide the result of BIM-Sustain, their research carried out with the help of Vienna University of Technology and about Seven BIM vendors of software developers or consultants.

Figure 2. Salient points of the BIM approach for sustainability

4.1 Green Building Assessment (GBA) Systems
The construction industry has changed its approach to sustainability due to building rating systems [35]. Various domestic and international green building certification programs are in effect to regulate the energy efficiency of construction projects [36]. The Building Research Establishment Environmental Assessment Method (BREEAM, UK) was the first building performance assessment system introduced in 1990. Some of the GBA systems are; Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), GreenStar (Australia), Building Environmental Assessment Method (BEAM) Plus, CASBEE (Japan), Green Star, Green Building Index (GBI), HQE (France) and Green Mark. The assessment by these GBA is based on the influences affected by energy consumption and efficiency, health concerns, daylight, indoor and outdoor environment, water and air, and life cycle assessment (LCA) [37].

4.2 Life cycle Assessment
LCA is the iterative procedure and an analysis of the environmental impact of the product on the surrounding world, spanning its whole lifetime [38]. BIM is a very relevant tool to address the LCA as any single element of a building can be parametrized and modeled separately [39]. [40] provide a methodology of integrating BIM and LCA tools that can be used in designing sustainable buildings. The method explains the development and implementation of the database incorporation in the model that stores the data about sustainable material. The model is linked to BIM, LCA, certification, and cost modules. [41] recommend the inclusion of LCA data in the BIM objects rather than using external databases to enhance the stakeholders’ understanding of the better alternatives about the environmental concerns in the early phases of the design process.

4.3 Site Location
It is not easy to evaluate the sustainability effects of location and distance to travel while designing green buildings. These assessments require a lot of manual calculations, experience, hard work, and time. BIM is now helping the stakeholders in getting green building certifications. However, as BIM applications lack strong mapping support, the location and transportation analysis by BIM is taken as improbable by many. [42] thus focus their research on the development of a framework that integrates technologies in
BIM and Web Map Service (WMS). They develop a BIM plugin for Autodesk Revit using Autodesk Revit and Google Maps APIs.

4.4 Lean Construction
The construction industry is witnessing fundamental changes due to its two important segments, the first being lean construction and the other BIM [43]. Much research is being done on BIM, lean construction, and construction sustainability not only singularly but in combination also. BIM has scheduling levels that help reduce cycle times. It is the outcome of several studies to indicate that BIM facilitated to implementation of both lean and green constructions [44]. The major purpose of lean construction is to maximize the customer value by reconceptualizing the construction process, to minimize, understand waste in any activity that consumes resources without creating any value, e.g., the mistakes that require rectifications, later on, unnecessary processing steps, purposeless transportation of goods and employees, etc. [45]. It is a control system for production planning that promotes all stakeholders to work in a team activity to generate a work process that results in higher productivity and dependable workflow [46]. The major contribution of [47] research is to explore the enhancement caused by lean implementation in the BIM maturity levels.

4.5 Off-Site Construction
BIM can leverage the benefits of off-site manufacturing as against the traditional construction that includes improved quality, safety, economy, work conditions, construction processed, sustainability with reduced waste, time, re-works with expected sustainability performance of the built assets [48]. However, the success of BIM lies in bidirectional data exchange among the different project stakeholders and the corresponding data in the BIM model [49].

4.6 BIM Software
BIM is generally perceived wrongly as a software program requiring high skills for advanced use of BIM [50]. Autodesk, Bentley Systems, and Graphisoft are major BIM software developers and providers. BIM is a process, and the strength of BIM lies in its interoperability and coordination as it involves the use and input from a myriad of software such as Revit for design, CADMep for MEP, Primavera for scheduling tasks, TEKLA for structures, DesignBuilder for sustainability analysis and Candy for pricing [51]. Other examples of the leading BIM solutions include Autodesk Architectural Desktop (ADT), Bentley Systems, Graph iSOFT’s ArchiCAD, among many others.

4.7 Flat Slabs
The residential, office, and other buildings in the industry extensively use the reinforced concrete flat plate slabs systems all over the world. The advantage of this lies in the reduction of the formwork cost, the time required, and the convenience of the installation [52]. The study by [53] examines the concrete structures for environmental performance by varying design parameters. The included various slab systems like flat slab and flat plates with different construction techniques and using traditional reinforcement and also post-tensioned methods. The outcome of design alternatives was considered in terms of embodied energy showing a decrease between 23.7% and 49.1% in the case of the post-tensioned construction system. Figure 3 shows a simplified building plan in their study.
[54] study the design and quantity take-off of automated virtual flat plate reinforced with S-BIM. [54] base their research on the interoperability among architectural and structural models, between structural analysis to structural analysis models and the design results that conform to the minimum thickness, deflection requirements in the concrete flat plates. Their study completes the numerical experiments for the automation of a flat plate in a 3D digital virtual model that includes reinforcement bars using structural BIM. Parametric design specifications and adoption of structural optimization during the initial stages of the workflow for better sustainability performance are expected to become more relevant as the BIM technologies are developed and adopted more and more in the design of buildings [55]. They study the automation for optimizing the reinforced concrete flat slabs for the reinforcement specifications process utilizing the data inputs from BIM and Finite Element Model (FEM) engine. The study by [56] analyses flat slab structures about their emissions and economic costs depending on the layout of columns and thickness of slabs. To assess the processes causing the equivalent carbon dioxide emissions, modeling of three different buildings with varying slab thickness was examined. They find that the permanently incorporated concrete and reinforcement material represents 85.5% of total emissions at their production stage. [57] opine that structural design implications have been ignored concerning the carbon performance of built assets in the previous studies. They address this prevalent limitation by presenting an integrated and structural analysis for sustainable building design. To achieve their goal, a BIM-based approach was devised by using embodied carbon metrics and the data from structural optimization.

5. Conclusion
This paper makes an effort to review the literature regarding the BIM approach to sustainable construction of buildings considering the flat slab models. The review in this article emphasizes the growing understanding of the integration of BIM and sustainability practices. As sustainable construction needs to minimize the waste quantities, BIM response in real-time to optimize the construction waste is the preferable option to the traditional data analysis techniques. Some models of flat slab buildings are generated by some studies where required parameters were assigned to different elements of the building. The embodied energy in these models was calculated and compared. A few benefits of using BIM approach, like the enhanced collaboration among stakeholders in the project, transparency in the design provided the visualization of the project model, data sharing, among others, have been highlighted in various overviews in this article. BIM can be used beneficially in the sustainable design of the buildings only by juxtaposing with proven prevalent project strategies. Though BIM has been there since the 1970s, BIM has yet to be exploited to its full potential even in leading contexts. Promising insights, however, signal successful embracing of BIM in the near foreseeable future. There is increasing awareness now to use modern digital tools like BIM.

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