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Building Design from an Environmental Perspective: A Review on Sustainable Building Design Models and Analysis of their Application in Practice

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Abstract

The construction sector is known for enormous resource consumption and the generation of solid waste. Considering construction is essential for economic development and for providing facilities to ever increasing populations around the globe, there is a need to make construction activities more environmentally friendly. As architects and technocrats are increasingly facing the need to achieve more sustainable and efficient buildings, they are empathizing with ways for reducing the environmental impact and consumption of energy in buildings. The present study aimed at reviewing various sustainable development models and technology initiatives like Building Information Modelling (BIM), Building Energy Modelling (BEM), Urban Building Energy Modelling (UBEM), and integrated frameworks like Circular Economy (CE) that enable improved environmental performance of the structures. Out of these models, the circular economy seems to be the most promising approach that can have a massive effect on the environmental impact of the buildings, but the concept is new and it requires industrywide restructuring at various levels.

Keywords

Sustainable building, Building Information Modelling, Building Energy Simulation, Integrated Design Process

1. Introduction

Construction projects use large amounts of natural resources and energy during all stages of their lifecycle. They also produce enormous amounts of waste, greenhouse gases (GHG), and contaminants. Building enterprises should thus consider how their construction and operations may affect the environment (Albertini et al., 2021). Sustainable Development Goals (SDGs) adopted by United Nations in 2015 address sustainable construction and India being a signatory to the 2030 agenda has taken several steps towards the same.

A nationwide tool giving guidelines for building construction activities is the National Building Code of India (NBC). The revised code brought out in 2016 has included Approach to sustainability. The draft Building Construction Environment Management Regulations 2022, which govern environmental management during

the construction of buildings, were released by India's Ministry of Environment, Forest and Climate Change (MoEFCC) in 2022. The project authority is required, by the draft Rules, to manage the environment, including managing solid waste, conducting tree planting, managing noise and air quality issues, managing soil erosion prevention policies, managing waterways at building locations, and adopting water conservation techniques. The project's governing authority must also provide evidence of conformity with these environmental requirements in the form of data and certificates (Kengo, 2022). As the regulatory frameworks are increasingly demanding sustainability in construction activities, all the stakeholders are consciously taking creative steps towards sustainable construction and green building practices. Advancement of technology has facilitated the development of sustainable design models for achieving energy efficiency, and environmental management in building construction without sacrificing the human comfort and quality of life.

2. The Concept of Sustainable Building

A sustainable building, also known as a green building, is the result of a design philosophy that emphasizes improving the efficiency of resource utilization while minimizing the effects of buildings on human health and the natural world over the course of their lifetimes via better siting, planning, building, operation, upkeep, and removal (Srinivas, 2015). Building Sustainability Assessment Systems (BSAS) have been established world over. The Green Building Rating Systems (GBRS) are mostly included in the BSAS. The most common GBRS are LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), Green Globe International Standard for Sustainability, and EDGE (Excellence in Design for Greater Efficiencies). The rating systems commonly used in India are IGBC (Indian Green Building Council) rating systems, and GRIHA (Green Rating for Integrated Habitat Assessment).

In addition to GBRS, there are several other BSAS. Multi-Criteria Decision-Making (MCDM) is one of the approaches that is most frequently used in developed and developing nations. Erdogan et al., (2019) describe how multi-criteria techniques may be used to tackle the major issues in building management. Setting objectives and identifying user needs, project restrictions, and requirements for resources are all part of managing a building venture. Olawumi et al. (2020) developed a multi-expert discussion process for the establishment of a GBRS in Nigeria, the biggest economy in sub-Saharan Africa. This was accomplished using structured questionnaire surveys and interview techniques. The comparison study demonstrates that while GBRS emphasize on the quality of environment and energy criteria, the BMAS (Building Management Assessment Systems) have a more comprehensive approach of considering the three fundamental pillars of sustainability viz. social, economic, and environmental.

3. Various Sustainable building design models

According to Munaro et al. (2020), natural resources are under a lot of strain due to their over exploitation by construction activities. The researchers conducted a systematic literature review consisting of 318 papers and stated that it is crucial that the construction sector shifts to a circular economy (CE). In order to implement circular concepts, government assistance, such as aid, legislation, and tax breaks, is essential. According to Najjar et al. (2019), compared to other sectors, the operating demand for buildings is one of the largest, making the use of electricity in buildings a crucial concern. To improve the operational energy usage of the generated building designs, the investigators created a unique framework for merging computational optimization, Building Information Modeling, and Life Cycle Analysis. The results show that by using the suggested model, yearly energy use magnitude can be decreased by approximately 45 percent, life cycle power utilization and expenditures can be decreased by over fifty percent, and effects on the environment like acidity and the potential global warming may be decreased by over thirty percent. According to Hollberg et al. (2020) building performance evaluations might be made easier with the use of building information modeling (BIM). Recently, tools that base Life Cycle Assessment (LCA) on the BIM model for automated quantity estimation have been created. Researchers reported using a BIM-LCA method to assess an actual building's combined global warming potential (GWP) during the entire design process.

BIM is opening new possibilities for overcoming the shortcomings of traditional construction energy modeling, such as laborious model planning, inconsistent models, and expensive execution, and it encourages the integration of building energy modeling through the computerized structure design process. Autodesk Revit, Design Builder, and IES- Virtual Environment are some of the popular BIM software. Through a review of the literature, it has been determined that BIM-based Building Energy Modelling (BEM) is especially appropriate for the initial design phase, in which the most appropriate and affordable methods for energy-effective design may be incorporated for the whole construction process (Gao et al., 2019). BEM is frequently employed in the construction sector for a variety of purposes, including complying with codes, optimization of designs, and retrofit evaluation. BEM-DRL, that utilizes deep reinforcement learning, is used for efficient HVAC design (Zhang et al. 2019b).

In urban areas, buildings use as much as 70 percent of a city's energy. Urban building energy modeling (UBEM) is a tool for urban energy planning that relies on both statistical and physical modeling approaches. A study by Ang et al. (2020) categorized UBEM proposals into 4 primary application groups: "urban planning and new neighborhood design, stock-level carbon reduction strategies, individual building-level recommendations, and

buildings-to-grid integration". The study offered a compiled UBEM process with information and process specifications.

It will be extremely desirable to integrate construction, urban design, and management with the skills of developing renewable energy frameworks to arrive at a holistic strategy for urban sustainability. A study, which employed a mixed approach, found that government laws regarding the reuse and recycle criteria for each new project may significantly enhance circularity in the construction sector. Circular construction recycling systems employ integrated eco-innovative solutions that combine sophisticated sensors and automated sorting to generate high quality circular products (Ghaffar et al., 2020).

Surrogate modeling, involving simulation, has previously been demonstrated to lessen the pressure on designers and engineers when evaluating designs for environmentally friendly buildings utilizing sophisticated performance analysis. It will be crucial in ensuring the sustainability of buildings in the years to come (Westermann & Evins, 2019). The heuristic aspect of machine learning is what the adaptive surrogate-driven technique depends on for algorithms based on data that enhance the models' prediction power (Gonçalves et al., 2020). Surrogate model can quickly provide efficiency estimations for millions of structure designs. The design space as a whole may be examined rather than just a few particular concepts, and architects can receive real-time input on how sustainable a building will be while working on it (Westermann, 2020).

4. Implementation of Sustainable building design models

According to Chan et al. (2019), over the past several years, BIM has gained more popularity in construction projects around the globe. The main obstacles to the use of BIM include the absence of BIM standards, insufficient institutional backing and framework for BIM, and building stakeholders' innate aversion to change. The main advantages include improved cost estimate and control, effective planning and administration of building projects, and an improvement in the design quality of the project. According to Oduyemi and Okoroh (2016), BIM methodology may bring significant advances in terms of planning and measuring the environmental impact of buildings. Building performance modeling (BPM) using Ecotect has shown to have significant promise for bringing uniformity to the collaborative building procedure. BPM may specify a clear setup for exchanging digital information. Zhang (2019a) pointed out that in the context of China, combining BIM with environmentally friendly buildings is an effective way to achieve sustainable development goals. The study suggested that policymakers should draft policies to enhance the implementation of BIM for sustainable buildings.

Ohueri et al. (2022) stated that due to the potential for green buildings to deliver excellent sustainability outcomes, financial savings, and health advantages to inhabitants, a growing number of customers are seeking them. 180 architects provided data for the study, which aimed to figure out the optimal BIM deployment strategies for the initial stages of environmentally friendly building design. The findings showed that choosing a qualified design team is the most effective strategy for using the BIM process in the design of green building processes; others being using software with strong compatibility to guarantee correct output, the creation of a standardized procedure for the use of the BIM process in the design of environmentally friendly buildings, and the prompt discovery of significant decision points. Tahmasebinia et al., (2022), created several regression models based on the outcomes of construction energy simulation. Autodesk Green Building Studio software, and Revit software were used for energy modeling. Sangi et al., (2019) created a Model Predictive Control (MPC) for structural energy systems that was installed in actual buildings to forecast upcoming stages of the system and control them. Kineber et al., (2022), conducted a study to reveal the potential of the implementation of robotics for sustainable building projects. The findings showed that the drivers of robotics have a low level, yet significant, impact on Nigeria's construction sector. Astarini & Utomo (2020), conducted a study to determine which performance-based building design (PBBD) criteria should architects and engineers use to develop and construct elevated apartment complexes in Indonesia. The researchers collected primary data from about 68 designers and engineers. The needs of the property's tenants, the management of the building, the collaborative design process, and the loss risk were all named as contributing considerations. Future studies are required to assess the effectiveness of the PBBD model and to incorporate the PBBD into BIM to enable compatibility.

Bourdeau et al., (2019) conducted a review of research on key methodologies for predicting and modeling the electricity consumption of buildings, with a focus on data-driven approaches. It was found that a common procedure that can address the wide range of issues encountered is still absent. Vázquez-Canteli et al. (2019), conducted a building energy simulation for insightful management of power in smart cities with the help of two case studies. Researchers have developed a novel simulation setting by combining TensorFlow, a potent machine learning, and CitySim, an urban energy model. The newly developed model system can create energy-efficient building scenarios where machine-learning techniques are used to address the main issues that contemporary cities are now facing. Li et al. (2019) conducted a study to integrate prefabricated housing productions (PHP) and BIM for better sustainability outcomes.

5. Conclusion

The present study tried to capture the essence of building design using novel technologies in improving the sustainability of the structure and extension to the urban areas around the globe. One essential tool is Building Information Modeling (BIM), which allows the stakeholders to optimize the planning, designing, and operating of the project, through software-based models. This virtual model provides consideration to the entire building lifecycle through real word data. Building energy modeling (BEM) is another such tool that is utilized for ensuring the energy efficiency of structures and forecasting the energy demand through computer models using real-world data. Urban building energy modeling (UBEM) can model the energy supply to entire cities or groups of buildings. It can effectively predict future energy requirements in quantitative terms considering weather-based variations. Among the most significant model that can enhance the sustainability is circular economy. The principles of circular economy enable the stakeholders to use the construction materials in a continuous loop in a manner that significantly reduces the material use and waste generation. It is currently a novel idea and requires restructuring the entire construction process and supply chain. The principles of circular economy are being adopted in the construction industry; however, complete circularity is yet to be achieved.

Considering the challenges associated with the adoption of these models in practice, more research based on case studies is suggested. Furthermore, these models are being used in the developed world, hence more studies should be conducted in developing and poor countries to identify the potential and challenges that are specific to these countries.

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