University of Southern Queensland

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Investigating energy efficient practices by using digital construction for green buildings

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In fulfillment of requirement of Bachelor of Construction (Honours)

October 2023

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Abstract

The construction industry significantly contributes to global energy consumption and carbon emissions. As concerns about climate change and environmental sustainability continue to grow, there is a pressing need to explore energy-efficient practices and sustainable solutions in the construction sector. Green buildings have emerged as a viable solution, aiming to minimize environmental impact while maximizing energy efficiency. In this research it digs into a critical study of energy-efficient practices within the field of green building, helped by digital construction approaches. The modern construction sector is seeing a change towards sustainable and ecologically responsible building practices. This research presents a comprehensive review of the subject, underlining the growing significance of energy efficiency & sustainability. Within this chapter empirical studies, applicable theories, and discover gaps will be investigated in the existing literature, establishing a foundation for a sound conceptual framework. The combination of theory and practice in this chapter gives readers, be they scholars, practitioners, or enthusiasts, vital insights into how digital construction might transform green architecture, ultimately leading to a more ecologically responsible and energy-efficient future. This study indicated several limitations, including inadequate BIM software capabilities, a lack of standardized processes and protocols, limited interoperability among software platforms, and insufficient BIM expertise. Similarly, explored the application of BIM in green building projects. The study indicated that digital construction methods could facilitate energy analysis, life cycle assessment, and sustainable design optimization. However, challenges were identified, including data integration, compatibility, and the need for standardized protocols.

Disclaimer page

Candidates Certification

I certify that the ideas, designs experimental work, results, analysis, and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other courses or institution, except where specifically stated.

Your Full date: Witharana Chanchala Navodani Rodrigo

Student: [redacted]

Date

Signature

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Abbreviations

BIM - Building Information Modelling

IoT – Internet Of things

HVAC – Heating Ventilation and Air conditioning

AEC-FM - Architecture, Engineering, Construction, and Facility Management

SDGs - Sustainable Development Goals

BPA - Building Performance Analysis

LoDs - Levels of Development

IFC - The Industry Foundation Classes

gbXML - Green Building Extensible Markup Language

LEED - Leadership in Energy and Environmental Design

BREEAM - Building Research Establishment Environmental Assessment Methodology

NZEBs - Net-Zero Energy Buildings

Chapter 01

1.0 Introduction

The construction industry has witnessed a rising focus on sustainability and energy efficiency, driven by the recognition of climate change and the imperative to curb carbon emissions. In response, green buildings have emerged as a vital solution to promote energy efficiency and mitigate environmental harm. Within this context, digital construction methods, including advanced technologies and Building Information Modelling (BIM), have demonstrated potential in facilitating the designing, construction, and operation of green buildings. Sustainable construction involves the construction, designing, and operation of buildings in a more environmentally responsible way (Gan et al., 2020). It aims to minimize the negative impacts of construction activities on the environment and maximize energy efficiency. Sustainable construction involves various aspects, including resource efficiency, waste reduction, renewable energy utilization, and improved indoor air quality. By adopting sustainable construction practices, buildings can save energy, reduce greenhouse gas emissions, and enhance occupant comfort and well-being.

Digital construction involves the integration of digital technologies and processes into the construction sector using technologies like virtual reality, BIM, IoT, robotics, and artificial intelligence (Zhang et al. 2019) . Digital construction enables improved collaboration, information sharing, and making decisions in the project execution. It offers numerous benefits, including enhanced productivity, reduced errors, cost savings, and improved project outcomes (Hafez et al., 2023). By leveraging digital construction methods, stakeholders can optimize building designs, including implementing energy-efficient practices. Green buildings are designed and constructed to reduce their environmental impact while promoting occupant health and well-being. They adhere to various principles, including energy efficiency, water conservation, use of sustainable materials, waste reduction, and indoor environmental quality (Uddin et al., 2021). Energy efficiency is a key aspect of green buildings, as it involves reducing energy consumption through efficient design, insulation, lighting systems, HVAC systems, and renewable energy integration. By incorporating energy-efficient practices, green buildings can significantly reduce energy usage, lower operating costs, and contribute to a sustainable built environment.

While digital construction methods offer promising potential for improving energy efficiency in green buildings, it is essential to investigate the practical outcomes and challenges associated with their implementation. Understanding the effectiveness of digital construction techniques in achieving energy efficiency goals and assessing their cost-effectiveness is crucial for informing industry professionals and decision-makers. This investigation will provide insights into the real-world application of digital construction for energy-efficient practices and bridge the gap between theoretical concepts and practical implementation. By identifying the barriers and opportunities associated with digital construction, this research aims to promote sustainable industrialization, foster innovation, and contribute to developing energy-efficient techniques for designers during the concept and design phases of green buildings (Hafez et al., 2023). Investigating energy-efficient practices using digital construction methods for green buildings is a timely and significant research endeavor. By aligning sustainable construction principles with digital technologies' capabilities, the construction industry can make substantial steps toward achieving energy efficiency and environmental sustainability. This investigation will provide valuable insights into the challenges, opportunities, and cost-effectiveness of implementing digital construction methods for energy-efficient practices, thereby advancing green building principles, and promoting a sustainable future.

1.1 Research objectives

The aim of this project is to investigate energy-efficient practices in the construction industry by utilizing digital construction methods for the development of green buildings. The specific objectives are as follows:

1. To investigate the implementation of sustainable industrialization for green building designs in the construction industry.
2. To develop energy-efficient techniques for designers during the concept and design phase of green buildings.
3. To assess how modern digital construction methods affect the progression of construction projects and identify practical issues associated with energy efficiency practices.

Chapter 02

2.1 Literature Review

The literature review provides a comprehensive overview of the current state of knowledge regarding energy-efficient practices in the construction industry, specifically focusing on the role of digital construction methods in the concept and design phase of green buildings.

2.1.1 Sustainable Industrialization and Innovation

Research has shown that sustainable construction practices can contribute to resource efficiency, waste reduction, and improved environmental performance (Hafez et al., 2023). Several studies have emphasized the importance of integrating sustainability principles into construction processes, highlighting the role of industry stakeholders, policymakers, and educational institutions in driving sustainable industrialization and encouraging innovation. For instance, Marzouk et al. (2022) indicated the potential of BIM to enhance the efficiency and effectiveness of green building systems, including improved coordination, enhanced decision-making, and streamlined communication. Steen's (2020) study also focused on the importance of sustainable industrialization and innovation in the construction industry. It discusses the role of resilient infrastructure in supporting sustainable development and achieving the SDGs (Steen, 2020).

The author identified various approaches and strategies to promote sustainable industrialization, such as circular economy principles, renewable energy integration, and green building practices. The chapter provides insights into the linkages between sustainable industrialization, innovation, and the SDGs, highlighting the role of the construction industry in driving positive change towards a more sustainable future. In December 2015 the Paris Agreement was implemented with 195 countries for international climatic actions to increase in the world-wide average temperature to fit below 2°C above pre-industrial levels and trailing efforts to limit the temperature rise to 1.5°C above pre-industrial levels (Fuglestvedt J. 2018). The Sustainable Development Goals (SDGs), and the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement desire to change the manner in which development disputes and climate change are referred.(Luis 2018).

Studies also presented challenges, such as data accuracy, model validation, and the need for standardized workflows (Meena et al., 2014). Therefore, this research provides insights into integrating green building systems into project delivery using BIM and identifies areas for further improvement and development in this field.

2.1.2 A Systematic Examination of the Development of Intelligent Building Representations from BIM to Digital Twins in the AEC-FM Industry

According to Deng *et al.* 2021, the shift from Building Information Modelling (BIM) to Digital Twins is the primary emphasis of this systematic review study on the development of intelligent building representations in the Architecture, Engineering, Construction, and Facility Management (AEC-FM) sector. To determine what technologies, support Digital Twins in the built environment, the authors combed through one hundred papers, including twenty-three reviews. The authors used Google Scholar, Scopus, and ScienceDirect to gather data relevant to their study by searching for terms like "BIM," "IoT," and "Digital Twin" in relation to "building." The articles that made the cut were subjected to qualitative scrutiny before being placed in a taxonomy that ranged from building information modelling (BIM) to the perfect Digital Twin.

The results show that building information modelling (BIM) for facility O&M is still in its infancy and confronts obstacles including data interoperability and financial justification (Hajj, 2022). However, simulations made possible by building information modelling are being used to improve construction processes, examine energy performance, and analyze thermal settings. Building design and operations can be improved with the help of these simulations. The remaining hurdles are data loss and incompatibility between BIM models and simulation systems. This article investigates how building information modelling (BIM) and Internet of Things (IoT) methods can work together in the building sector (Tang *et al*. 2019). Applications such as construction process monitoring, energy performance management, indoor environment monitoring, indoor thermal comfort, space management, hazard monitoring, and community monitoring are highlighted as examples of how this integration might be put to use.

Improving decision-making and efficiency throughout the building life cycle is highlighted as a key benefit of real-time data collecting and visualization. The article also suggests the characteristics and skills of future-generation Digital Twins and highlights gaps in the current body of information. It classifies prior studies according to their application levels and research topics, giving a thorough overview of the present state-of-the-art methodologies in implementing Digital Twins. The authors wrap up by detailing the desired characteristics of a state-of-the-art Digital Twin for controlling the climate inside a single building. This study offers a thorough analysis of the transition from building information modelling to the Internet of Things-enabled digital twins in the built environment. It clarifies the existing technological landscape and highlights opportunities for future exploration. The results provide new insight into the capabilities and limitations of Digital Twins in the context of facility management.

2.1.3 Sustainable Development and How Green Hotel Practises can help bring it about

According to Abdou *et al.* 2020, in order to achieve Sustainable Development Goals (SDGs) in the hospitality business, this article examines the role that green hotel practices play. The study focuses on the perceptions of environmental management staff in Egyptian hotels that have earned the Green Star certification, as well as their opinions on how green practices can help achieve the SDGs for clean water and sanitation, access to affordable and clean energy, responsible consumption and production, and climate action. According to the study's conclusions, putting into practice green hotel practices helps to achieve the SDGs. The majority of respondents said that water conservation and waste management techniques helped hotels contribute to SDG 6 (clean water and sanitation) through their operations. In some SDG 6 targets, there were statistically significant variations between four and five Green Star hotels, nevertheless. The survey also demonstrates that while hotels are proactive in putting green practices relating to waste management, water conservation, and energy saving into practice, the usage of renewable energy sources like solar and wind energy is less widespread. According to the article, hotel owners can make a stronger commitment to environmental sustainability by holding training sessions to raise employee involvement and knowledge. Sharing best practices among hotel owners and routine follow-up by Green Star organizations can both strengthen a commitment to sustainability.

The need to integrate green practices into hotel operations to achieve environmental sustainability is emphasized in the essay. Because of its high resource use and trash production, the hotel sector substantially negatively influences the environment. Financial rewards, client requirements, and stakeholder interactions all influence the adoption of green practices in hotels. Major hotel groups are putting more emphasis on their dedication to sustainability. The essay emphasizes the necessity for hotels to use green practices in order to fulfill consumer expectations, aid in environmental preservation, and advance SDGs (Rubio-Mozos *et al*. 2020). In order to apply sustainable practices in the hotel business, it emphasizes the significance of effective communication tactics, stakeholder pressure, and eco-control systems. Additionally, the article includes a list of sources on energy and water conservation, hoteliers' environmental views, customers' preferences for eco-friendly features, and potential advantages of recycling in the hotel industry.

2.1.4 Analysing how building information modelling (BIM) fits into the larger context of project performance analysis

According to Jin *et al.* 2019, this study offers a thorough analysis of the integration of Building Performance Analysis (BPA) and Building Information Modelling (BIM) in the project life cycle. The study uses a variety of research techniques, such as bibliometric analysis, content analysis, and qualitative discussion, to examine the state of this field's research at the moment. Interoperability, semantics, and sustainability grading systems are the three key topics of the study. With a focus on data formats like IFC and gbXML, interoperability difficulties between BIM and BPA systems are discussed. The study emphasizes the significance of including BPA at every stage of a project's life cycle and promotes the creation of an extensive indicator system for sustainable building. In addition to reviewing current research on BIM integration with BPA, the study specifies important input qualities and workflow in BPA. In particular, interoperability difficulties are examined along with other important study fields. Discussion of the potential discrepancy between "as-designed" and "as-built" building performance emphasizes the necessity of better performance and communication in construction projects.

The paper highlights the value of BIM and BPA compatibility and recommends future research avenues to strengthen this interoperability. It recommends integrating BIM and BPA at every stage of a project's life cycle and suggests using Levels of Development (LoDs) to streamline information interchange. In its last section, the article makes recommendations for future research initiatives, including case studies and the application of BIM-enabled BPA to other facets of sustainability. With a focus on overcoming interoperability concerns and boosting communication and performance, this paper offers a thorough overview of the integration of BIM and BPA in building projects. The study underlines the significance of including BPA at every stage of a project's development and identifies possible directions for further study, including the use of deep-learning neural networks and big data to BPA in green structures. The results of this study can help to create procedures for designing and maintaining buildings that are more effective and sustainable.

2.1.5 Analysis of 34 Case Study Buildings' Efforts to Achieve Net-Zero Energy Use in High-Humidity Environments

According to Feng *et al.* 2019, this research analyses the design processes, technology selections, and energy output of 34 NZEBs located in different countries. These results show that in addition to other energy-efficient and renewable energy technologies, NZEBs in hot and humid areas frequently use passive design approaches and technologies including daylighting and natural ventilation. Numerous "net-zero energy" case studies show extremely low energy consumption intensities, with some even going so far as to become "net-positive energy." Not all NZEBs are created equal when it comes to energy efficiency, and even those with extensive usage of renewable energy sources might have a high energy use intensity. The article goes into the particular architectural and envelope, HVAC, lighting, plug load, and renewable energy technology options for NZEBs in hot and humid areas. It emphasizes the use of high-performance wall and roofing systems, as well as onsite vegetation, high-performance glazing, natural ventilation, energy-efficient lighting, and energy-efficient appliances.

The study also found that NZEBs in hot and humid areas had construction prices that were around double the baseline costs for typical new buildings in the US market. The study delves into the importance of smart controls and user control in attaining zero-energy targets, the operation and maintenance of NZEBs, and the integration of renewable energy generation into the power grid. This study highlights the need to optimize NZEB performance and integrated design, especially in hot and humid regions. Policy recommendations for boosting NZEB development are presented, including the adoption of advanced technology, the removal of impediments, and the implementation of supportive policies, based on an analysis of the energy performance of selected NZEB case studies. The publication also includes suggestions for where future research should go and discusses the study's limitations. Solar heating and cooling, insulation, shading devices, lighting controls, and smart grid technologies are only a few of the many topics covered in the list of references provided. This study highlights the need for additional research and cost-effective initiatives to promote NZEBs in developing regions, while also providing useful insights and best practices for obtaining high-performance NZEBs in hot and humid conditions.

2.2 Theories and Models

Modern architectural and construction practices must include both building performance analysis (BPA) and building information modelling (BIM) (Yu *et al*. 2022). These innovative methods have fundamentally altered the way structures are created, constructed, and maintained by offering a comprehensive approach to construction projects. This comprehensive review examines the convergence of BIM and BPA and provides insight into the theories and models that underpin it. The report evaluates the current level of research in this dynamic field using a number of research methods, including bibliometric analysis, content analysis, and qualitative discussion.

2.2.1 The Integration of BIM and BPA: A Theoretical Framework

The integration of BIM and BPA is driven by the knowledge that a thorough approach to construction projects, integrating design, analysis, and performance, may produce more productive, affordable, and sustainable outcomes (Pishgar *et al*. 2021). Interoperability, semantics, and sustainability grading systems are the three main focuses of the theoretical framework that supports this integration.

2.2.2 Interoperability: Bridging the Divide

The foundation of their integration is the compatibility of the BIM and BPA technologies. The Industry Foundation Classes (IFC) and Green Building Extensible Markup Language (gbXML) are two distinct data formats that are used by BIM and BPA applications to operate (Ohueri, 2022). In order to convey vital data about building design and performance, data must be able to flow between different systems without interruption. This is where interoperability challenges reside. According to the interoperability idea, when BIM and BPA tools can operate together without a hitch, the design and analysis processes become more unified, and the project gains from better data consistency. Without interoperability, the integration of BIM and BPA will not be possible, hence this theoretical foundation is essential.

2.2.3 Semantics: A Common Language for Sustainability

In the context of BIM and BPA, semantics refers to the uniform use of language and data structures to assist in building performance analysis over the course of a project (Xun *et al*. 2022). Performance analysis can only be carried out consistently and successfully if there is a common understanding of the data and its meaning. A thorough indicator system for building sustainability must be created, according to the theoretical foundation of semantics, in order for BPA to be effortlessly integrated into BIM. The use of a uniform language guarantees that sustainability objectives are reached, and that performance analysis is included in the planning and building stages.

2.2.4 Sustainability Rating Systems: A Roadmap to Sustainable Buildings

A road map for achieving sustainable building design and construction is provided by sustainability grading systems like LEED and BREEAM (Marchi *et al*. 2021). According to the theoretical underpinnings of sustainability rating systems, these systems shouldn't exist independently of BIM and BPA but rather should be incorporated into the design and analysis processes. Achieving the targeted sustainability goals becomes more doable when BIM and BPA systems can align with the standards established by sustainability rating systems. To design environmentally conscious and energy-efficient buildings, this theoretical approach emphasizes the significance of a positive interaction between sustainability rating systems, BIM, and BPA.

2.2.5 Input Attributes and Workflow: A Model for Seamless Integration

The identification of crucial input attributes and workflows is a crucial part of integrating BIM with BPA (Marmo *et al*. 2019). The theoretical basis for the seamless integration model is the idea that input properties, such as building data and performance indicators, should be constant and easily available over the course of a project. This theoretical framework emphasizes the necessity of a clear methodology that guarantees performance analysis is a continuous process rather than a one-time occurrence. In order to educate design choices and improve building efficiency, the model envisions a constant flow of data and information between BIM and BPA.

2.2.6 Interoperability Enhancement: The Levels of Development (LoDs) Approach

To improve interoperability between BIM and BPA, the Levels of Development (LoDs) approach is suggested. This theoretical framework contends that information transmission can be made more controllable by specifying precise LoDs that spell out the degree of precision and detail of information in BIM (Boyes, 2021). The process of incorporating BPA into the project life cycle is made simpler when BIM models and related data are consistently organized according to LoDs. In order for BIM and BPA to collaborate seamlessly to assist in building performance analysis, this theoretical framework promotes a standardized method of data transmission.

2..3 Future Research Directions: Expanding the Horizons

In order to progress the integration of BIM and BPA further, the paper's conclusion highlights potential future study areas. Utilizing Big Data and deep learning neural networks for BPA in green buildings is one possible route. According to this theoretical viewpoint, in the future, improved data analytics and artificial intelligence will be crucial in determining and enhancing building performance. It is also suggested to use BIM-enabled BPA for other sustainability-related topics, like energy and water saving (Anwar, 2022). This theoretical framework proposes that the integration of BIM and BPA can go beyond its existing limitations, fostering a more thorough strategy for the design and upkeep of sustainable buildings.

2.4 Energy-Efficient Techniques for Designers

Several studies have focused on energy-efficient design strategies, highlighting the role of architects and designers in achieving energy-efficiency goals. Yuan et al. (2017) indicated that “Bionic Green Architecture” and “Bionic Building Energy Efficiency” have effectively promoted energy-efficient techniques in the construction industry. The study explored the concepts of bionic building energy efficiency and bionic green architecture, where the finding indicates that the application of biomimicry and nature-inspired design principles enhances energy efficiency and sustainability in the built environment. Some of the benefits of these designs include optimized ventilation systems, passive cooling strategies, and energy-efficient façade designs inspired by natural systems (Lotfabadi et al., 2016). The study also discusses the challenges and prospects of integrating bionic design concepts into green architecture.

According to Li et al. (2018), stakeholder impact analysis significantly affects green building evolution. While the study focuses on the post-occupancy evaluation, it indirectly contributes to the objective of developing energy-efficient techniques for designers during the concept and design phase of green buildings. Several studies have explored various design aspects, including building orientation, envelope design, daylighting, natural ventilation, energy-efficient HVAC systems, and renewable energy integration (Jalaei & Jrade, 2014). Studies have shown the potential of digital tools and techniques in supporting energy-efficient design decisions and enhancing collaboration among project stakeholders (Haruna et al., 2021). For instance, the advancements in digital construction methods, such as BIM, have facilitated optimizing design processes by enabling accurate energy simulations, modelling, and performance analysis.

2.5 Impact of Digital Construction Methods on Project Progression

Modern digital construction methods affect construction project development. Research has highlighted the benefits of digital construction, including improved communication, reduced errors, enhanced project coordination, and increased productivity (Basbagill et al., 20134). According to Gerrish et al. (2017), the development of constructive projects has been affected by digital construction methods like BIM. In this study, the calmness challenges faced in traditional energy modelling methods were examined how BIM capabilities could address these challenges. The study highlighted that BIM could improve accuracy, data integration, and collaboration in energy modelling processes (Gerrish et al., 2017). Keirstead et al. (2012) identified potential challenges, such as training and upskilling, interoperability issues, data privacy concerns, and integrating digital tools with existing workflows. However, applying BIM in green building projects would address this issue through project planning, cost reduction, and better facility management. Therefore, addressing these practical issues effectively is crucial for successfully implementing digital construction for energy-efficient practices.

2.6 Literature Gap

Most of what has been written on sustainable development & green hotel practices focuses on how these eco-friendly activities might help bring about the SDGs. However, there is a clear void in the literature regarding the difficulties of applying these eco-friendly practices in the hospitality sector, especially in countries like Egypt where they are gaining popularity. The views of Egyptian hotels' environmental management staff that have been certified Green Star are illuminated by this empirical investigation. It highlights the ways in which green practices contribute to the SDGs, but it also hints at some of the subtle variations in reaching certain SDG targets. To fill this knowledge vacuum, researchers need to look more closely at the barriers that prevent hotels from embracing renewable energy and other eco-friendly practices (Najjar *et al.* 2019). Hotels would benefit from a better understanding of these obstacles since it would lead to better methods for encouraging sustainable practices, easing the attainment of SDGs, and encouraging environmental preservation. There is a noticeable hole in the literature when it comes to the long-term operational performance and user behaviour elements of Net-Zero Energy Buildings (NZEBs) in hot and humid conditions. Existing studies mostly concentrate on how NZEBs are built, what technologies are used, and how much energy they produce at first.

This empirical research is primarily concerned with design and construction costs and the need for policy suggestions, although it does offer useful insights into the architectural, HVAC, lighting, & renewable energy technology used in these buildings. To fill this knowledge vacuum, researchers need to examine what happens to NZEBs after their original occupants move out, especially in humid and hot areas. Long-term energy efficiency and net-zero energy goals of these buildings can be improved by analyzing the effects of user behaviour, maintenance, and smart controls. To ensure the long-term viability of NZEBs and to develop thorough recommendations for optimizing their performance, it is essential to have a thorough understanding of the practical obstacles and possibilities that occur once NZEBs are operational (Nguyen and Macchion, 2022). Policymakers, and architects, while construction operators working towards environmentally friendly construction practices in hard conditions will benefit greatly from this type of study.

2.7 Conclusion

In summary, this literature review provides an overview of the relevant research investigating energy-efficient practices using digital construction methods for green buildings, Overall this chapter on reviewing the literature has offered a thorough synopsis of studies on green building and environmentally friendly hotel operations. The potential for green hotel practices to contribute to Sustainable Development Goals has been emphasized, and the transition from BIM to Digital Twins in the AEC-FM business has been proven. On the other hand, it has brought to light some major holes in the current literature, most notably on the impact of user behavior and the long-term operational performance of sustainable buildings, which emphasizes the importance of promoting sustainable industrialization, developing energy-efficient techniques for designers, and assessing the impact of digital construction methods on project progression. More research is needed to fill these knowledge gaps and inform policymakers and professionals in the field. This research project aims to advance energy-efficient practices in the construction industry and support the development of sustainable, environmentally friendly green buildings.

Chapter 03

3.0 Research Methodology

The construction industry significantly contributes to high global energy consumption and carbon emissions, making exploring energy-efficient practices and sustainable solutions imperative. Innovation has led to the emergence of green buildings that are designed to minimize environmental impact and maximize energy efficiency and have emerged as a viable solution to address these challenges. Digital construction methods, with their potential to optimize design, construction, and operation processes, offer opportunities to enhance energy efficiency in green buildings (Uddin et al., 2021). However, there is a need to investigate the practical outcomes and challenges associated with implementing energy-efficient practices using digital construction methods. There is a need to understand the effectiveness of digital construction techniques in achieving energy efficiency goals and identifying potential barriers and opportunities for their implementation.

The research aims to evaluate the positive outcomes of energy-efficient practices in green buildings that utilize digital construction methods by assessing the reduction in energy consumption, carbon emissions, and operational costs achieved through the integration of energy-efficient design, advanced technologies, and digital construction processes. The investigation also sought to identify the challenges faced during the implementation of digital construction for energy-efficient practices and analyze the cost-effectiveness of implementing digital construction methods for energy-efficient practices in green buildings. This involves assessing the upfront investment required, potential long-term savings in energy costs, return on investment (ROI), and the economic viability of incorporating energy-efficient design strategies enabled by digital construction. Addressing these research questions will contribute to advancing sustainable construction practices, facilitating informed decision-making by industry professionals, and guiding the successful implementation of energy-efficient practices using digital construction methods.

According to Engineers Australia and the relevant board of Surveyors, several ethical considerations were implemented during the literature review. Such as environmental, social, and economic aspects. First, minimize biases in the selection and interpretation of studies to maintain the integrity of the review process. Proper citation and attribution of sources were essential to avoid plagiarism and respect intellectual property rights. Researchers should appropriately acknowledge and credit the original authors and sources of information. The research methods, search strategies, inclusion/exclusion criteria, and data analysis processes were clearly documented to ensure transparency and enable the replication of the study. This helped adhere to the principles outlined in these codes of ethics and ensured that the research project was conducted ethically and aligned with professional standards.

The research adopted a descriptive research methodology to investigate energy-efficient practices in the construction industry by assessing the studies focusing on utilizing digital construction methods to develop green buildings.

This research aimed to gather, analyze, and synthesize existing literature related to energy-efficient practices, digital construction, and green building principles to achieve this aim. Several steps were taken to develop a comprehensive resource plan for a systematic review. Firstly, an extensive literature search should identify relevant research materials. This involved searching academic databases, contacting experts in the field, and exploring grey literature sources. Secondly, we obtained subscriptions, memberships, or permissions to ensure access to the identified research materials. Additionally, networking platforms such as research forums, academic conferences, and online communities were utilized to connect with researchers and gain insights into ongoing studies or unpublished data. Collaboration with other researchers or research institutions was utilized, which was beneficial in sharing resources and accessing additional research materials. Finally, maintaining a well-organized database or reference management system helped manage and reference the collected research materials throughout the systematic review process.

The review process involved comprehensive literature research across various academic databases, journals, and relevant sources. The keywords and search terms included energy efficiency, digital construction, sustainable construction, and green buildings, were used to identify relevant studies. The inclusion and exclusion criteria involved studies published from 2017 to date and in English were established to ensure the selection of studies aligned with the research objectives. After the initial literature search, several articles were screened based on titles and abstracts. Five studies; by Steen (2020), Wakeford et al. (2017), Singh (2018), Yuan et al. (2017), and Sepasgozar & Davis (2019) were selected. The selected studies were then subjected to a full-text review to assess their relevance and quality. Data extraction was performed to collect information on the selected studies' research focus, methodologies, findings, and implications. The collected data were analyzed and synthesized to identify common themes, patterns, and trends related to energy-efficient practices, digital construction, and green building principles.

The project has made significant progress in the last months. The literature review has been completed, and the positive outcomes and challenges associated with energy-efficient practices have been identified. The questionnaire has been developed and obtained the University Human Ethics Committee's approval before it is administered. The case studies have been conducted to compare the energy efficient practices using digitalization in the United States, China, Egypt, and Australia

Also, data collection and analysis of the questionnaire and investigations of energy efficient practices by using digital construction for green buildings have been documented.

4.0 Risk Assessment

Risk assessment is important in identifying potential challenges and risks and the ways to mitigate such challenges (Junkes et al., 2015). The following risk assessment was conducted to identify potential risks and challenges that may have arisen during the project.

Table 1: Risk Assessment

Type	Risk/Challenge	Severity	Impact	Mitigation
Data Availability and Quality	Insufficient availability of relevant and reliable data on energy-efficient practices and digital construction methods.	High	Medium	Conduct a thorough literature review to gather comprehensive data from reliable sources. Collaborate with industry professionals and experts to gather real-world data and insights.
Technical Challenges	Technical complexities and challenges associated with implementing digital construction methods and energy-efficient techniques.	Medium	Medium	Engage with experienced professionals in the field, consult with experts and stay updated with the latest technological advancements. Allocate sufficient time for training and upskilling to overcome technical challenges
Stakeholder Resistance	Resistance from stakeholders, such as designers, contractors, or clients, to adopt digital construction methods and energy-efficient practices	Low	Low	Communicate the benefits of digital construction and energy efficiency, highlighting cost savings, environmental benefits, and improved project outcomes. Provide training and support to stakeholders to ensure smooth adoption and address any concerns or resistance.
Time Constraints:	Limited time for conducting comprehensive research, analyzing data, and completing the project within the allocated timeframe.	High	High	Develop a realistic project timeline, prioritize tasks, and allocate resources effectively. Regularly check the progress and make adjustments as necessary. Plan and manage time efficiently to ensure all project objectives are met.
Cost Considerations	Financial constraints and budget limitations for implementing digital construction methods and energy-efficient techniques.	Medium	Low	Conduct a cost-benefit analysis to demonstrate the long-term cost savings associated with energy efficiency. Explore funding opportunities or partnerships with organizations interested in promoting sustainable practices. Optimize resource allocation and identify cost-effective solutions.
Ethical Considerations	Potential ethical dilemmas, such as data privacy concerns, conflicts of interest, or potential bias in the review process	Low	Low	Adhere to ethical guidelines and codes of conduct outlined by professional bodies. Ensure informed consent, protect data privacy, maintain objectivity and transparency, and disclose any potential conflicts of interest.

5.0 Results and Discussions

In this section, we have reviewed and discussed the results for the systematic review and compared practical solutions and industrial-based problems with green building concepts identified from literature based on journal articles and online resources. The first objective analyzed promoting sustainable industrialization and fostering innovation in the construction industry. The findings by Steen (2020) and Wakeford et al. (2017) indicate that the construction industry can achieve this by integrating energy-efficient techniques and digital construction methods; the project seeks to revolutionize the way buildings are designed, constructed, and operated.

The construction industry must encourage the use of environmentally friendly materials, renewable energy sources, and efficient construction processes (Steen, 2020). Wakeford et al. (2017) argued that it needs to adopt sustainable construction practices, such as waste reduction, recycling, and responsible resource management. Lastly, sustainability can be enhanced by advocating for implementing green building standards and certifications to ensure sustainable development in the industry. Fostering innovation in the construction industry is to promote research and development of advanced technologies for energy-efficient and sustainable construction (Steen, 2020). This involves facilitating collaboration among industry stakeholders, researchers, and innovators to share knowledge and drive innovation (Wakeford et al., 2017). The project also supports implementing digital construction methods, BIM, and advanced data analytics to enhance project outcomes and efficiency.

The following figure indicates how the universal use of energy consumption and common energy intensity of active controllers in buildings is expected to differ in the year 2040

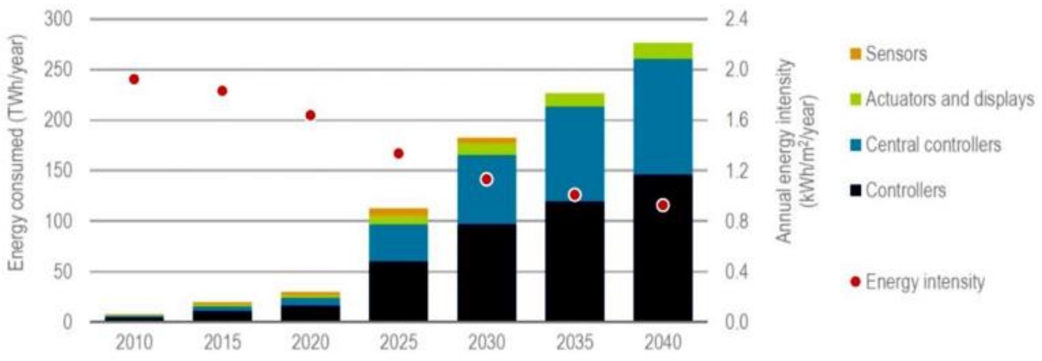

Figure 1 Global energy use and average energy intensity of active controls in buildings (IEA & Digitalization and Energy Working Group, 2017)

For the second objective, there were several energy-efficient techniques for designers during the concept and design phase of green buildings. Energy-efficient techniques for designers during the concept and design phase of green buildings encompass various strategies to reduce energy consumption and promote sustainability. Passive design techniques involve maximizing natural lighting, ventilation, and shading to minimize the reliance on artificial lighting and cooling systems (Singh, 2018). Building envelope optimization focuses on designing an efficient envelope with high insulation, air sealing, and proper orientation to minimize heat transfer and energy loss. Yuan et al. (2017) indicate that using bionic green architecture and bionic buildings are some energy-efficient designs that promote sustainability. Efficient HVAC systems selection involves choosing energy-efficient heating, ventilation, and air conditioning systems with advanced controls and zoning capabilities. Renewable energy integration entails incorporating on-site renewable energy sources like solar panels, wind turbines, or geothermal systems (Yuan et al., 2017).

Efficient lighting involves using energy-efficient fixtures like LED bulbs and smart lighting controls. Water conservation strategies include implementing water-saving fixtures, rainwater harvesting systems, and efficient irrigation methods. The material selection focuses on choosing sustainable and eco-friendly materials with low embodied energy and high durability. Life cycle assessment is employed to evaluate the environmental impact of materials and systems throughout their life cycle. By integrating these techniques, designers can create energy-efficient, sustainable, and environmentally friendly buildings.

Lastly, it was vital to find out how modern digital construction methods affect the progression of construction projects and identify practical issues associated with energy efficiency practices. The study by Sepasgozar and Davis (2019) emphasizes the importance of adopting digital construction technologies and demonstrates how these technologies can improve project efficiency, accuracy, and communication among stakeholders. It investigates the challenges and practical issues of implementing digital construction methods, including integrating BIM and other advanced technologies. The research provides insights into the factors influencing the successful adoption of digital construction technologies, such as effective relationship strategies between technology providers, contractors, and other industry stakeholders (Sepasgozar & Davis, 2019). It highlights the potential benefits of using digital tools for energy efficiency practices, such as improved energy modelling and analysis capabilities during the design and construction phases.

The case study findings reveal that advanced Sustainable buildings located in China were able to achieve the completion of projects in less time frame. A 220-floor building and a 30-story building were able to be completed within 90 days and 15 days respectively (Evans-Greenwood et al. 2019). Also, the case studies depict some key advantages of using Digital technologies for construction such as facilitating material traceability (Chen et al., 2020, p. 472). The research by Wang et al. (2017) introduced a "BIM-RFID framework" to maximize the precision of the coordinate points of the concrete structures. Furthermore, digital technologies adapted to maximize the building and appliance performance by concerning energy efficiency to the state energy evolution by introducing smart meters and digital twins. (United Nations Economic Commission for Europe, 2021).

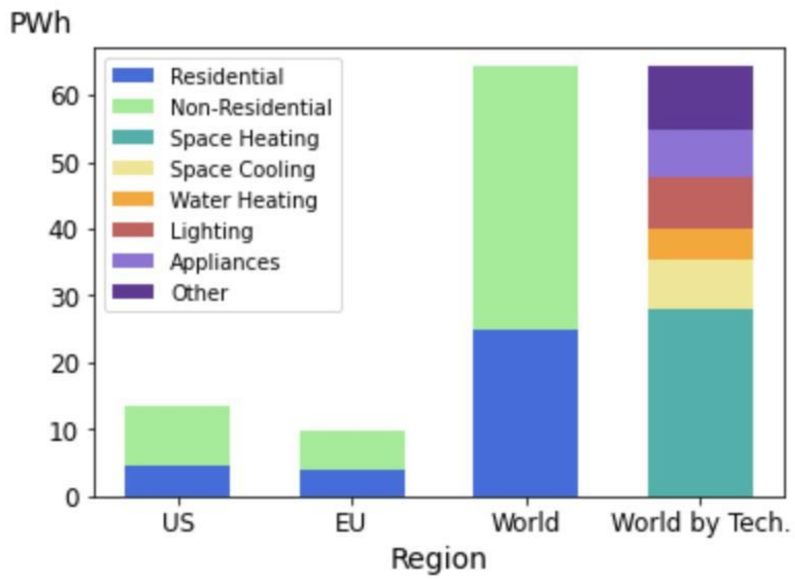

Figure 2 Cumulative energy savings in buildings from widespread digitalisation between 2017 and 2040

(IEA & Digitalization and Energy Working Group, 2017)

5.1 Data analysis

Data analysis on investing in energy-efficient practices using digital construction for green building, a survey was conducted among various professionals in the construction sector. The survey included questions related to their educational qualifications, years of experience, company specifications, the presence of energy-efficient practices in their projects, challenges faced during implementation, use of digital construction techniques, and their opinions on the subject. The survey results are presented below:

Participant Information:

1. **Timestamp**: Various timestamps are recorded for each participant.
2. **Designation**: Participants include individuals with different roles such as Project Manager, Engineer, and others.
3. **Educational Qualification**: Participants have qualifications ranging from Certificate III/IV to bachelor’s degrees.
4. **Years of Experience in the Construction Sector**: Experience levels vary from less than 1 year to 5-10 years.
5. **Company Specification**: Participants come from different types of companies, including contractors and others.
6. **Category of the Organization**: Companies are involved in Commercial, Residential, Infrastructure, or other types of projects.
7. **Type of the Organization**: Some companies are private entities.

Energy Efficiency and Digital Construction:

8. **Does the Project Design Comprise Energy-Efficient Practices?** All the participants reported that their projects incorporate energy-efficient practices.
9. **If yes, what are Energy-Efficient Practices Used in Your Project?** Participants mentioned various practices, including passive design techniques, photovoltaic systems, energy modelling and simulation tools, and high-performance building envelope designs.
10. **What Are the Challenges Occurred When Implementing Above Options?** Challenges include lack of experienced professionals, lack of training, unsupportive organizational culture, resistance of employees, technical challenges, budget constraints, and IT security issues.

Digital Construction Techniques:

11. **Are There Any Digital Construction Techniques Used in Your Project?** All participants reported using digital construction techniques in their projects.
12. **How Far Are You Using Digitalization at Work?** Participants have varying levels of digitalization in their work, from not influencing to highly influencing.

Smart Controls and Technologies:

13. **What Smart Controls are Available in Your Building?** Participants mentioned the use of actuators, displays, central controllers, smart meters, and other technologies.
14. **What Technologies and Software Programs are You Using in Your Project?** Technologies such as BIM, Energy Management Systems, digitally connected devices, and the Internet of Things are mentioned.
15. **What Computational Methods and Platforms are You Using in Your Construction Project?** Advanced control algorithms, cloud databases, and machine learning are reported as computational methods and platforms.

Comments and Observations:

16. **Do You Have Any Other Comments or Observations Regarding Energy-Efficient Practices by Using Digital Construction?** One participant expressed the need for more emphasis on energy-efficient practices in day-to-day construction practices.

Educational Qualifications and Professional Experience: The participants exhibit a range of educational qualifications, encompassing both certificate holders and individuals with bachelor's degrees. This observation implies that there is a presence of persons with varied educational backgrounds within the construction industry. Furthermore, the spectrum of professional experience, spanning from less than one year to 5-10 years, highlights the consolidation of novices and seasoned practitioners within the business.

The Implementation of Energy Efficiency Measures

One notable observation is that a majority of participants indicated the integration of energy-efficient practices into their projects, demonstrating a congruence with the prevailing global inclination towards sustainable construction. The main energy-efficient practices employed encompassed passive design approaches, solar systems, and energy modelling. These practices have the potential to substantially decrease energy usage in buildings and mitigate their carbon emissions.

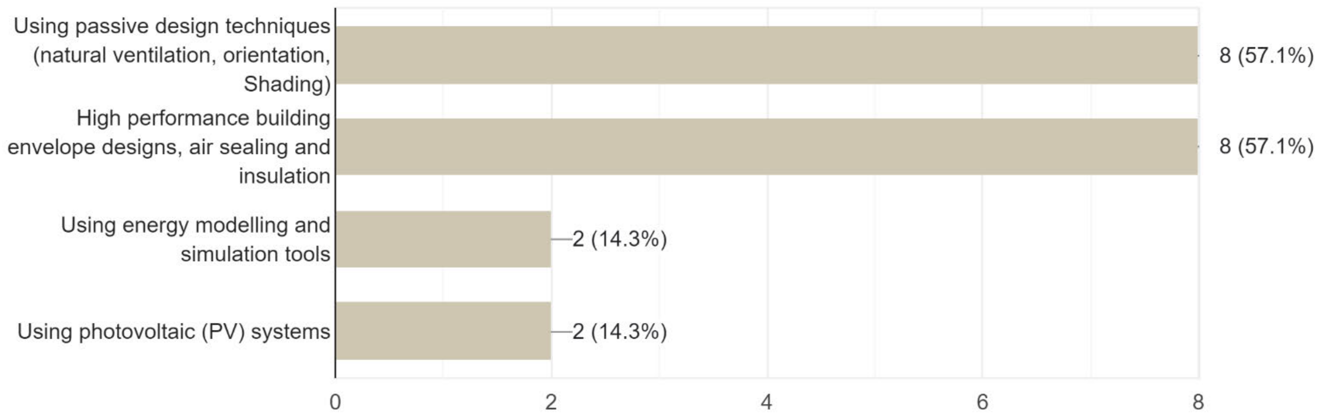

Figure 3 The energy efficient practices used in projects which Queensland based

The difficulties encountered during the process of implementation:

A wide range of problems were found in the implementation of energy-efficient practices. The challenges encompassed a variety of factors including a shortage of proficient specialists and adequate training, as well as obstacles stemming from organizational culture, employee opposition, technical complications, resource allocation, and financial limitations. The aforementioned problems highlight the necessity of adopting a holistic approach that encompasses both the technical and organizational dimensions of green construction initiatives.

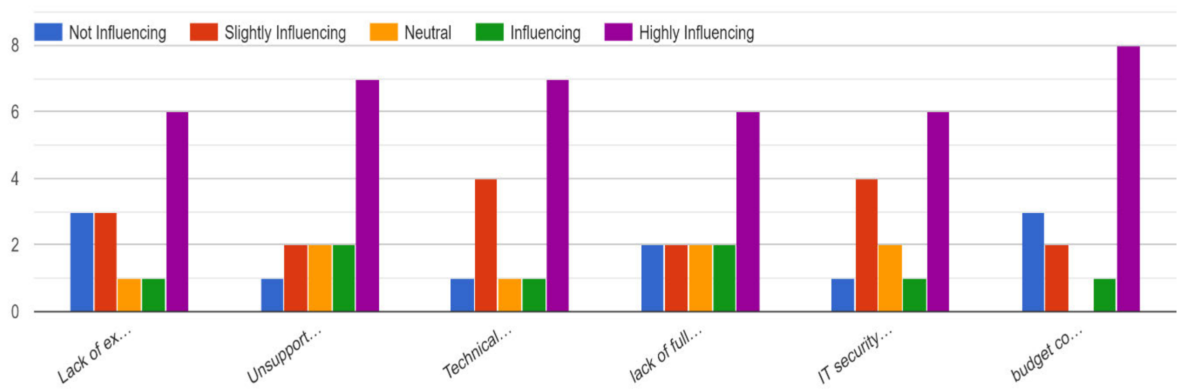

Figure 4 the challenges affecting when implementation of digital techniques

The utilization of digital construction techniques

All participants expressed the use of digital building approaches, so demonstrating the industry's acknowledgement of the advantages of digital tools in augmenting efficiency, precision, and sustainability. The diverse range of influences on the work of participants indicates that although digitalization is widespread, there exists potential for more implementation and enhancement of digital tools.

Smart Controls and Technologies refer to a range of advanced systems and devices that incorporate intelligent features to enhance control and management processes. These technologies are designed to optimize efficiency, improve performance, and streamline operations in several domains,

The study participants indicated their utilization of a diverse range of intelligent control systems and technological devices, including sensors, actuators, central controllers, and smart meters. The utilization of these technologies is of utmost importance in the monitoring and regulation of energy usage within buildings, thereby leading to enhanced energy efficiency.

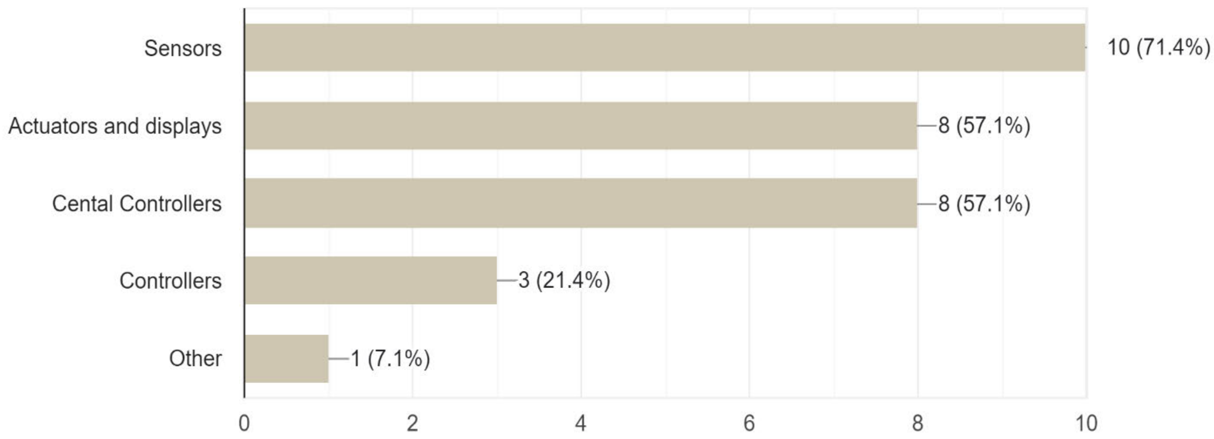

Figure 5 The percentage of smart controls used in buildings

The utilization of technologies and computational methods.

The participants referred to the utilization of sophisticated technology such as Building Information Modelling (BIM), Energy Management Systems, digital interconnected devices, and the Internet of Things (IoT). The inclusion of computational techniques such as machine learning and advanced control algorithms suggests the incorporation of state-of-the-art technologies to improve energy efficiency.

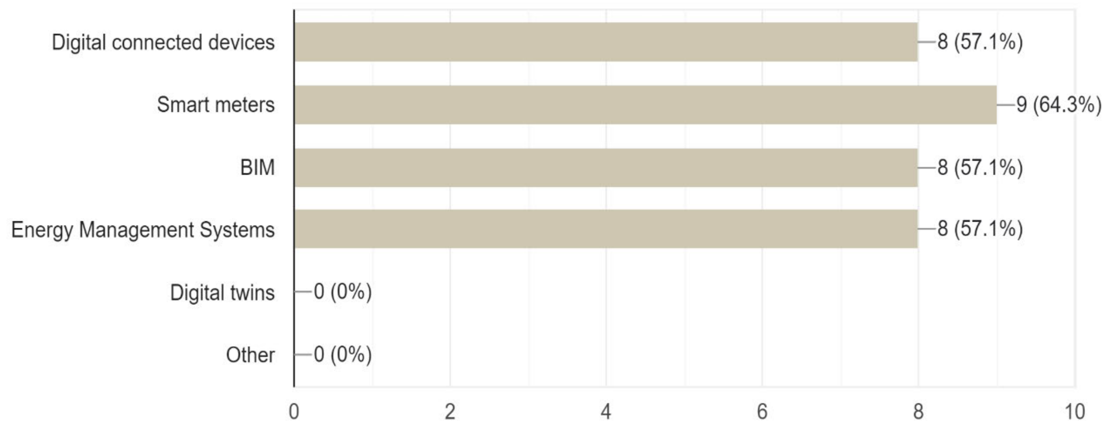

Figure 6 The percentage of technologies and software used in Queensland based projects

5.2 Observations

One of the participants articulated the perspective that there should be greater emphasis on the incorporation of energy-efficient practices in routine construction procedures. This comment underscores the necessity of heightened awareness and education within the sector to foster the significance of environmentally friendly construction methods and digitalized construction technologies.

Educational Diversity and Experience: The educational diversity of the participants is notable. While some have achieved bachelor's degrees, others possess Certificate III/IV qualifications. This diversity can be seen as an opportunity for knowledge sharing and cross-pollination of ideas. Collaborative efforts between experienced professionals and those just starting in the field could lead to innovative solutions and the widespread adoption of energy-efficient practices.

Energy Efficiency Implementation: The prevalence of energy-efficient practices, including passive design techniques, photovoltaic systems, and energy modelling, highlights the industry's commitment to sustainability. This commitment is crucial in reducing the environmental impact of construction projects. The variety of techniques used also showcases the adaptability of the industry to different environmental conditions and project requirements.

Challenges in Implementation: The array of challenges faced during implementation is a clear call for comprehensive support. Addressing these challenges, such as a lack of experienced professionals and training, organizational culture resistance, and budget constraints, requires a multi-faceted approach. Investment in training and education, fostering a culture of sustainability, and promoting the business case for energy-efficient construction could help alleviate these challenges.

Digital Construction Techniques: The universal use of digital construction techniques is a positive sign of the industry's modernization. Digital tools not only enhance efficiency but also enable real-time data collection, analysis, and decision-making, which is crucial for optimizing energy consumption in buildings.

Smart Controls and Technologies: The integration of smart controls and technologies like sensors, actuators, central controllers, and smart meters reflects the growing trend of adopting IoT solutions in construction. These technologies offer precise monitoring and control, which is essential for maintaining energy-efficient building operations.

Technologies and Computational Methods: The use of advanced technologies such as BIM, Energy Management Systems, digital connected devices, and machine learning indicates the industry's commitment to staying at the forefront of technology. By adopting these tools, construction professionals can optimize building designs and operations for maximum energy efficiency.

Comments and Observations

The participant's comment regarding the need to highlight energy-efficient practices more in day-to-day construction operations is noteworthy. It emphasizes the importance of raising awareness within the industry about the benefits of green building practices and digital construction. This can be achieved through training programs, industry seminars, and knowledge sharing.

8.0 Conclusion

In conclusion, the literature review findings from the systematic review and risk assessment indicate that digital construction methods, particularly BIM, can potentially enhance energy-efficient practices in green buildings. Integrating digital technologies such as BIM, IoT, artificial intelligence, and virtual reality can optimize the design, construction, and operation processes, resulting in improved energy efficiency and environmental sustainability. Sustainable industrialization and innovation are essential to promote energy-efficient practices in the construction industry. Stakeholders, policymakers, and educational institutions have significant roles in driving sustainable construction practices and fostering innovation. Investing in training and upskilling is crucial for successfully adopting and implementing digital construction methods.

Architects and designers play a key role in developing energy-efficient techniques during the concept and design phase of green buildings. By incorporating bionic building energy efficiency principles, bionic green architecture, and nature-inspired design, designers can optimize various aspects such as building orientation, envelope design, daylighting, natural ventilation, HVAC systems, and renewable energy integration. Digital tools like BIM can support energy-efficient design decisions and enhance collaboration among project stakeholders. Adopting digital construction methods can positively impact project progression by improving communication, reducing errors, enhancing project coordination, and increasing productivity. However, challenges such as data integration, interoperability, and standardized workflows must be addressed by investing in training, and upskilling is essential to fully leverage the benefits of digital construction for energy-efficient practices fully.

Further research activities will study how industry professionals and decision-makers adopt digital construction methods, particularly BIM, to enhance energy-efficient practices in green buildings. The literature findings indicate this requires training programs, knowledge sharing, and collaboration among stakeholders. Also, educational institutions should include sustainable and digital construction methods in their curriculum to prepare future professionals with the necessary skills and knowledge to drive energy-efficient practices in the construction industry.

Further research should address gaps and challenges, such as data availability and quality, technical complexities, and stakeholder resistance. Research efforts will be focusing on developing solutions and best practices to overcome these challenges and promote the successful implementation of digital construction methods for energy efficiency. Besides, Funding agencies and organizations interested in promoting sustainable practices should provide financial support and incentives for adopting digital construction and energy-efficient practices. This can help overcome financial constraints and encourage widespread implementation of energy-efficient design strategies.

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APPENDIX

Survey

INVESTIGATE THE ENERGY EFFICIENT PRACTICES BY USING DIGITAL CONSTRUCTION FOR GREEN BUILDINGS

I am Witharana Chanchala Rodrigo, undergraduate student at University of Southern Queensland, QLD, Australia who is following Bachelors of Construction (Honours) program. I am conducting research to find out energy efficient practices by utilizing digital construction methods for the design and construction of green buildings.

Furthermore, I am specifically focusing on the construction industry in Queensland. Information of your response will not be passed to anyone and will be only used for my undergraduate research. Your response is highly appreciated, and thank you in advance for spending time to support.

u1122458@umail.usq.edu.au Switch account

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* Indicates required question

A. Participant Details

1. Designation the participant (Ex: Director, Project manager, Engineer, Architect, Quantity Surveyor etc.)

- ○ Director
- ○ Project Manager
- ○ Engineer
- ○ Architect
- ○ Quantity Surveyor
- ○ other

3. Educational Qualification

- ○ PHD
- ○ Masters
- ○ Bachelors
- ○ Diploma
- ○ Certificate III, IV
- ○ Other

Years of experience in Construction sector

- ○ Less than 1 year
- ○ 1-3 years
- ○ 3-5 years
- ○ 5-10 years
- ○ More than 10 years

B. Participant's Company Details

2. Company Specification

- ○ Contractor
- ○ Client
- ○ Other

3. Category of the Organization

- ○ Government
- ○ Private
- ○ Other

4. Type Of the organization

- ◯ Commercial
- ◯ Ressidential
- ◯ Infrastructure
- ◯ Commercial And Ressidencial
- ◯ Other

C. Evaluation of Energy efficient practices

6. Does the Project design comprise energy efficient practices?

- ◯ Yes
- ◯ No

7. If yes, what are energy efficient practices used in your project? *

- ☐ Using passive design techniques (natural ventilation, orientation, Shading)
- ☐ Using energy modelling and simulation tools
- ☐ High performance building envelope designs, air sealing and insulation
- ☐ Using photovoltaic (PV) systems
- ☐ Other: ____________

8. What are the challenges occurred when implementing above options ?

	Not Influencing	Slightly Influencing	Neutral	Influencing	Highly Influencing
Lack of experienced professionals and lack of training					
Unsupportive organizational culture together with resistance of employees					
Technical challenges including struggle to asses IT needs					
lack of full understanding on choosing the right resources					
IT security issues such as data misuse					
budget constraints					

Digital Construction for energy efficiency

10. Are there any digital construction techniques used in your project?

- [ ] Yes
- [ ] No

11. How far are you using the digitalization at work?

- [ ] Very Less
- [ ] Moderate
- [ ] Mostly

12. What smart controls are available in your building?

- [ ] Sensors
- [ ] Actuators and displays
- [ ] Cental Controllers
- [ ] Controllers
- [ ] Other

13. What technologies and software programs using in your project?

- [ ] Digital connected devices
- [ ] Smart meters
- [ ] BIM
- [ ] Energy Management Systems
- [ ] Digital twins
- [ ] Other

14. What computational methods and platforms using in your construction project?

- [ ] Internet Of things
- [ ] Advanced Control Algorithms
- [ ] Machine Learning
- [ ] Cloud databases
- [x] High performance computing
- [ ] Other: ______

15. Do you have any other comments or observations from your current role or organization, regarding energy efficient practices by using digital construction? Please comment your opinion below.

Your answer ______