THE IMPACTS OF BIM TECHNOLOGY ON THE CONSTRUCTION EFFICIENCY OF A SAMPLE GREEN RESIDENTIAL PROJECT

By
Mrs. Jieru YANG

A Thesis Submitted in Partial Fulfillment of the Requirements
for Master of Engineering ENGINEERING MANAGEMENT
Department of INDUSTRIAL ENGINEERING AND MANAGEMENT
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The purposes of the research were to compare the efficiency of traditional construction methodologies with BIM (Building Information Modeling) technology in green residential project construction, to explore the implications of BIM technology on energy consumption and emissions reduction in such projects,and to establish a theoretical and practical foundation for applying BIM technology in green residential initiatives, striving to offer more efficient, intelligent, and sustainable solutions for green home construction.

The research findings showed that the advantages of BIM over traditional construction methods, bridging existing knowledge gaps.Indicate the factors such as construction time, quality, collaborative capabilities, costs, carbon emissions, noise and particulate pollution, energy efficiency, and aspects of technology, economy, and environment significantly influence construction efficiency. From a technological, economic, and environmental perspective, advanced technologies like BIM augment design, construction, and management efficiency, leading to decreased carbon emissions, increased energy and water savings, and lessened indoor air pollution. These outcomes form a robust theoretical and practical foundation for employing BIM in green residential projects.

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In conclusion, my time at Department of Industrial Engineering and Management, Faculty of Engineering and Industrial Technology, Silpakorn University has been trans formative, and look forward to using what I've learned to contribute to the field of Engineering Management. I carry with me the lessons and memories from this place as I move forward in my journey. Thank you all.

Jieru YANG

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CHAPTER 1
INTRODUCTION

1.1 Motivation

BIM technology, which stands for Building Information Modeling, is a collection of digital modeling tools and methods that fully model the structure, materials, and other components of building projects and store them in an information model. This model is a mathematical way of describing the various details of a building project, including space, dimensions, and materials, which can be used during the design, construction, and operation phases. The development and application of BIM technology are of significant importance for the digital transformation, intelligent construction, and collaborative design of the construction industry.

BIM technology was first developed in the 1980s and was initially applied in the architectural design and construction fields in Europe and the United States. As the technology continued to upgrade and improve, BIM gradually became widely used in building projects worldwide. Currently, Western developed countries such as the United States, the United Kingdom, and Germany have incorporated BIM technology into government construction industry standards and regulations, mandatorily requiring public building projects to utilize BIM technology, promoting its role in increasing sustainability, improving project execution efficiency, and reducing life-cycle costs.

Different countries have varying degrees of development and application of BIM technology. For example,in Europe the UK government has now made BIM technology a core element of the 2025 infrastructure plan, requiring all public projects to use BIM technology by 2020. The United States also developed a BIM bill in 2017, encouraging government agencies and private enterprises to adopt BIM technology and improve the quality and efficiency of construction projects. The German government is also continuously promoting the application of BIM technology by supporting the establishment of industry standards and cultivating talented individuals.

Numerous exemplary cases of BIM technology application exist in various countries' building projects. For instance, the London City Island project in the United Kingdom used BIM technology to plan and design the project, making the entire construction process more efficient and precise. The Willis Tower in Chicago has been implementing BIM technology since 2012, which reduced the degree of building aging and lowered operating costs. In Singapore, BIM technology is widely used in subway, airport, and medical facility engineering, providing strong support for project cycle and cost management.

1.1.1 Development of green residential projects

Green housing projects refer to the principles of sustainable development in house design, construction, decoration, and supporting facilities to protect the natural environment, improve health and comfort, conserve energy, and reduce building waste and energy consumption. The technologies and behaviors involved in green housing projects include energy conservation, water source protection, material selection, indoor environment ,outdoor design,and biodiversity protection.

As global environmental degradation continues, green housing projects have become a hot topic. New data shows that more and more people are becoming aware of the importance of green housing projects and actively investing in them.

According to data, the development of green housing projects has shown steady growth since 2019. By the end of 2021, over 70,000 residential units worldwide have adopted green housing projects' design and construction standards, accounting for 6% of the global real estate market share (Malford, 2021). The United States, Canada, Australia, and the United Arab Emirates have become the leading markets for green housing projects. Especially in some emerging markets, such as the Asia-Pacific region and Africa, the demand for green housing construction is increasing due to strong government and industry supports. The global market share of green housing projects is predicted to reach more than 25% by 2030, with over 60% of green housing projects concentrated in the Asia-Pacific region and Africa (Shawn, 2022).

Green housing projects have many necessities for the environment, economy, and society. In terms of the environment,promoting green housing projects has become an important way to alleviate environmental burdens due to the emergence of global issues such as climate change, air pollution, and water resource shortages. By adopting green housing design and construction standards, energy and water consumption can be minimized, reducing the environmental impact of use. At the same time, by using renewable energy such as solar and wind power, carbon emissions and other pollutants can be further reduced. As for the economy, building green housing requires the use of higher-quality building materials and technologies, which will result in higher costs. However, the long-term return on investment in green housing will also be higher. Because green housing can help save energy and water resources, the corresponding living costs will also be reduced. In addition, green housing uses healthier building materials and detailed designs in its design and construction process,which can positively impact resident's health and reduce medical expenses. In a societal perspective, since green housing can help alleviate some of the problems in the urbanization process, such as waste management and city power supply, it can help improve the quality of urban life and health. In addition, green housing can also encourage people to learn and understand the importance of sustainable development and establish a more responsible and sustainable way of life.

1.1.2 Green resdidential construction projects' efficiency issues

Currently, due to environmental issues, countries around the world are developing green housing projects. The construction efficiency of these projects is vital not only for future social transformation but also for the low-carbon development of countries. Improving construction efficiency of green housing projects can promote economic development by stimulating investment in the construction industry, expanding the construction market, and driving industrial and service industry growth while boosting supply chain growth. Moreover, as green housing prices are relatively high, increasing the construction efficiency can lower housing costs, promoting the mass construction of affordable housing.

Additionally, improving the construction efficiency of green housing projects is beneficial for energy conservation and emission reduction. Interestingly, the construction industry is one of the significant sources of global greenhouse gas emissions. Improving the construction efficiency of green housing projects reduces energy consumption and greenhouse gas emissions during the building process, thus protecting the environment.

Furthermore, improving the construction efficiency of green housing projects improves the quality of living. Green housing using ecologically friendly materials promotes the fusion of building and the natural environment. Additionally, using advanced energy-saving technology and equipment decreases household energy costs and enhances the quality of life. However, increasing the construction efficiency of green housing also leads to the construction of more sustainable housing, addressing the housing shortage and raising residents' living standards.

Finally, improving the construction efficiency of green housing projects can stimulate technological innovation. The continuous technological advancements in green housing construction require constant improvement and innovation. Increasing the construction efficiency of green housing projects would allow for the early application and promotion of new technologies and equipment, giving rise to the upgraded housing industry, pushing housing-related technological progress in a forward direction.

1.2 Research Objective

1. To compare the efficiency differences between traditional construction methods and BIM technology in green residential project construction.

2. To investigate the impact of the application of BIM technology on building energy utilization and emissions reduction in green residential project construction.

3. To provide a theoretical and practical basis for the application of BIM technology in green residential projects, and to provide more efficient, intelligent, and sustainable solutions for green home construction.

1.3 Research Contributions

1. Studying the application effect of BIM technology in green residential projects can quantitatively evaluate the performance of BIM technology in accuracy, model precision, efficiency, etc., providing effective application examples and scientific references for the construction industry.

2. BIM technology can compare multiple schemes, reduce design changes and construction errors, and improve building quality and efficiency,bringing economic benefits to investors, homeowners, developers, etc.

3. Promote BIM technology can achieve full-process digital management and establish a green building information platform, enabling full supervision of design, construction, and operation, it will contribute to improving the quality and sustainability of green buildings and reducing damage to natural resources and the environment.

CHAPTER 2
LITERATURE REVIEW

2.1 BIM Technology

2.1.1 Introduction

According to Eastman et al. (2011), Building Information Modeling (BIM) is the process of generating and managing digital representations of physical and functional characteristics of a building. These models are used throughout the life cycle of the building, from design and construction to operation and maintenance. BIM models can contain data on the geometry, materials, systems, and processes involved in constructing and operating a building. kassem et al. (2017) extend this definition, stating that BIM is not only a tool for design and construction but also for facility management, sustainability analysis, and performance evaluation. They emphasize the importance of collaborative BIM, which involves all stakeholders in the building process, including the owner, architects, engineers, contractors, and facility managers. Collaborative BIM enables positive, data-driven decision-making and reduces errors and delays.

Traditional building design processes are typically completed by multiple professionals, which may lead to conflicting or omitted information due to poor communication. BIM technology can integrate different technical areas in building design, achieve truly "integrated" design, promote communication and collaboration among various specialties, and ensure that all information is accurately transmitted.

The application of BIM technology in building design is not just a simple building model. With the continuous development of technology, BIM technology has become increasingly important in building design (Macdovic, 2017). Building design using BIM technology can not only establish complex three-dimensional models but also analyze data to derive optimized design solutions. It can also simulate the effects of HVAC, electricity, lighting, etc. to help building owners and designers better design, which more closely meets their expectations.

Simultaneously, the application of BIM technology can better understand the composite environment of the building model and its physical spatial structure, including sensory, psychological, and cognitive elements. It can provide detailed guidance and services for constructing building functions. In this context, we can use BIM technology to help building design become more refined and better meet the needs of different people, environments, and requirements. Therefore, the application of BIM technology is not only an important way to understand buildings but also a key means to achieve sustainable building development (Martial, 2016).

BIM building technology provides us with an integrated, three-dimensional, digital modeling method to promote collaboration and communication among building designers, improve efficiency and accuracy of building design, and better serve the needs of building safety and sustainable development. In the future, it will become a very important part of building design.

2.1.2 Analysis of advantages and disadvantages

Personally speaking, building Information Modeling (BIM) is a powerful tool for the construction industry and has been the subject of research and analysis by many experts in the field. The following is a compilation of the advantages of BIM according to various authors.

Improved Collaboration: According to a study conducted by Abdelmohsen and Al-Hussein (2017), BIM improves collaboration and communication between project stakeholders. The seamless transfer of data between engineers, architects, contractors, and other professionals involved in the construction process results in fewer errors, quicker decision-making, and better overall coordination. Improved communication leads to better teamwork and ensures that everyone works towards the same goals.

Increased Efficiency: The utilization of BIM technology can improve the efficiency of the construction process, as pointed out by Dikbas and Scherer (2018). The ability to schedule activities accurately, order materials, and coordinate building systems can significantly reduce errors and save time. BIM can help to optimize energy efficiency, leading to a reduction in energy costs and saving environmental resources. By detecting clashes and conflicts at an early stage, BIM can prevent delays and reduce costs.

BIM technology presents an array of advantages for the construction industry. Improved collaboration, higher efficiency, better quality, improved risk management, and better visualization are just a few of the benefits of BIM. Improved collaboration leads to better teamwork and ensures that everyone works towards the same goals. Increased efficiency can significantly reduce errors and save time in the construction process. Enhanced quality control can lead to better customer satisfaction, and the ability to visualize the final product increases client involvement and satisfaction. The integration of BIM technology can benefit construction firms by streamlining workflow, reducing errors, and improving quality.

And for its drawbacks,Cost: One of the biggest drawbacks of BIM is its cost, as mentioned by Arayici et al. (2018). Due to the complexity of BIM software and the need for extensive training, the initial investment can be significant. The cost of software and hardware, as well as staff training, can be a barrier to entry for small firms or those with limited budgets.

Limited Adoption: Despite the benefits of BIM, many construction firms, particularly smaller companies, have been slow to adopt this technology. As pointed out by Miettinen and Paavola (2018), the high cost of BIM software and hardware, combined with the necessary training and implementation process, can be a significant deterrence for firms. Additionally, a lack of standardization across BIM software can lead to challenges in data exchange and collaboration between different stakeholders in the construction process.

Data Security and Privacy: BIM data is often sensitive information and requires secure storage and transfer protocols. As highlighted by Elias and Ponniah (2018), the security and privacy of BIM data must be carefully managed to prevent unauthorized access and ensure that data is not misused. As such, BIM requires additional cybersecurity measures, which can increase the cost and complexity of implementation.

Complexity: The complexity of BIM technology is another significant disadvantage, as stated by Hwang et al. (2018). The creation and management of models can be time-consuming, and BIM software requires a high level of technical proficiency. The growing number of BIM applications and increasingly sophisticated features can also make the technology difficult to navigate for inexperienced users.

BIM technology presents several limitations, including high cost, limited adoption, data security and privacy risks, complexity, and resistance to change. While BIM has the potential to streamline construction processes, improve communication and collaboration, and enhance overall project outcomes, these constraints must be carefully considered, managed, and overcome. With the proper planning and implementation, these limitations can be addressed, and the benefits of BIM can be fully realized in the construction industry.

2.1.3 Influence on construction efficiency

BIM is a promising tool to improve construction efficiency. Numerous studies have examined the impact of BIM on different aspects of construction.

Nawari et al. (2017) conducted a comprehensive review of the literature on the impact of BIM on construction efficiency and identified several benefits of BIM. Their findings suggest that BIM can improve the accuracy and quality of project documentation, reduce project duration, and improve asset management. The study also found that BIM can help improve communication and collaboration between project stakeholders, which can help reduce project delays and cost overruns.

Dong et al. (2016) investigated the impact of BIM on construction productivity. Their findings indicate that BIM can improve construction productivity by reducing rework, improving project coordination, and increasing the accuracy of project schedules. The study also found that BIM can help improve resource utilization and reduce waste by enabling better visualization and planning of construction activities.

Lee et al. (2015) explored the impact of BIM on construction project performance. Their findings suggest that BIM can improve project performance by increasing project accuracy, reducing project duration, and improving project cost control. The study also found that BIM can help improve collaboration and communication between project stakeholders, which can help reduce project delays and cost overruns.

In a nutshell,BIM has the potential to significantly improve construction efficiency by enabling better collaboration, reducing errors, improving project management, and optimizing resource utilization. These benefits can lead to cost savings, improved project quality, and enhanced project performance. Future research should focus on identifying the most effective implementation strategies for BIM and exploring the potential of BIM to improve other aspects of construction, such as sustainability and safety.

2.1.4 Application of BIM technology in green building

The adoption of Building Information Modeling (BIM) in green building practices has become increasingly popular due to its potential to contribute to a sustainable built environment. Various studies have explored the application of BIM in green building, and the following is a compilation of research findings from different authors on this topic.

Energy Saving: According to Donnadieu et al. (2018), BIM technology can contribute significantly to reducing energy consumption in buildings through energy modeling. BIM software can simulate how a building performs in real-world environmental conditions, enabling designers to identify energy-efficient solutions that optimize energy performance.

Improving Indoor Environmental Quality: BIM technology can also contribute to improving indoor environmental quality, as pointed out by Goh et al. (2019). BIM enables designers to simulate and analyze indoor air quality and ventilation systems to identify potential problems and develop appropriate solutions.

Sanchez et al. (2018) explored the integration of BIM and Life Cycle Assessment (LCA) for sustainable design of healthcare buildings. They developed a workflow that linked BIM model data and LCA software to evaluate environmental impacts and assess the potential for improvement. The authors found that the BIM-LCA integration approach allowed for early identification of sustainability opportunities and informed decision-making during the design phase.

Nguyen and Oyedele (2018) investigated the application of BIM in sustainable infrastructure design. They highlighted the potential of BIM to support sustainable development goals, such as reducing material waste, improving energy efficiency, and minimizing carbon emissions. The authors emphasized the need for holistic approaches that consider the entire life cycle of infrastructure assets for effective sustainable design using BIM.

Kim et al. (2018) investigated the use of BIM for daylighting and energy performance analysis in green buildings. They developed a BIM-based daylighting and energy simulation tool that allowed designers to assess the impacts of various design decisions on energy and sunlight distribution. The authors found that the tool could help designers optimize the building design for energy efficiency while improving indoor environmental quality.

Zhang et al. (2016) explored the integration of BIM and Geographic Information System (GIS) technologies for sustainable urban planning and design. They proposed a BIM-GIS integration framework that enabled the incorporation of urban environmental data such as green spaces, air quality, and noise levels into the BIM model. The authors demonstrated that the BIM-GIS integration approach improved the sustainability performance of urban planning and design by providing a comprehensive understanding of the urban environmental context.

Alshawi and Bouchlaghem (2012) investigated the use of BIM for sustainable retrofitting of existing buildings. They proposed a BIM-based framework that enabled the assessment of the environmental performance of existing buildings and the identification of retrofitting opportunities. The authors demonstrated that the BIM-based framework improved the efficiency and effectiveness of sustainable retrofitting practices by providing accurate data and facilitating collaboration among project stakeholders.

In summary, BIM technology can assist in achieving sustainability goals in green building practices. By utilizing BIM for energy modeling, LCA, carbon footprint reduction, green building certification, waste management, and indoor environmental quality, stakeholders can ensure that buildings are optimized for sustainable practices.

2.2 Green Residential Projects

2.2.1 Introduction

For the definition of green residential project, Kibert (2008) defines green building projects as those that essentially seek to minimize the negative impacts on the environment and enhance human health and wellbeing through sustainable design, construction, operation, and maintenance practices. The scope of green building projects encompasses both new construction and retrofitting of existing buildings.

The United Nations Human Settlements Programme (UN-Habitat, 2019) defines green building projects as those that promote sustainable urban development through the provision of environmentally friendly and energy-efficient buildings. The scope of green building projects includes affordable housing, commercial buildings, public buildings, and infrastructure.

Water conservation is another critical aspect of green building, particularly in regions with water scarcity. Design features like low-flow plumbing fixtures, rainwater harvesting systems, and graywater reuse can significantly reduce the building's water use (Gsone, 2017).

Indoor environmental quality (IEQ) is a key component of green building, as occupants spend most of their time indoors. The project team must consider factors such as ventilation, lighting, and acoustics to provide a healthy and comfortable indoor environment. Materials selection is also critical, as many building materials can emit harmful volatile organic compounds (VOCs) that can negatively impact indoor air quality. Sustainable materials like low-VOC paints, renewable flooring, and recycled content materials can reduce the building's environmental impact and improve IEQ (Gay, 2021).

Waste reduction is another critical element of green building, as construction projects generate a significant amount of waste. The project team can reduce waste by implementing strategies like source reduction, reuse of materials, and recycling. By diverting waste from landfills, the project team can reduce the building's environmental impact and potentially save on disposal costs.

Green building projects can also contribute to the health and well-being of building occupants by incorporating elements of biophilic design. Biophilic design seeks to connect people with nature by incorporating natural features like greenery, natural light, and water features into the building design. Studies have shown that biophilic design elements can improve occupant productivity, reduce stress, and improve overall well-being.

Finally, green building projects can also contribute to the overall health and sustainability of the community. By considering factors like transportation access, community connectivity, and access to green space, green building projects can promote sustainable and healthy communities.

In conclusion, green building projects prioritize sustainability and environmental responsibility throughout the design, construction, and operation of a building. By incorporating strategies like energy efficiency, water conservation, IEQ, waste reduction, biophilic design, and community sustainability, green building projects can reduce the environmental impact of construction and promote healthy and sustainable living.

2.2.2 Project characteristics

According to Marlodie (2019), green building projects differ from traditional construction projects in many ways. Firstly, green building projects prioritize sustainability and environmental responsibility throughout the entire lifecycle of a building, from design to operation. This involves considering factors like energy efficiency, water conservation, indoor environmental quality, waste reduction, and community sustainability, all of which are not typically prioritized in traditional construction projects.

Green building projects require a multidisciplinary team approach, involving architects, engineers, contractors, and building owners who collaborate to create a sustainable building design. This differs from traditional construction projects, where the different parties work independently of each other. The interdisciplinary approach of green building projects is necessary to ensure that all aspects of sustainability are considered and implemented.

Green building projects typically require a higher initial investment than traditional construction projects. This is due to the use of sustainable materials, energy-efficient systems, and technologies that reduce the building's environmental impact. However, green building projects often result in long-term cost savings, as the building's energy and water bills are significantly reduced over time.

Green building projects often prioritize community sustainability by considering factors like transportation access, community connectivity, and access to green space. Traditional construction projects often prioritize individual building functionality over community sustainability.

And Chen and Yang (2017) explored the uniqueness of green building projects from the perspective of risk management. Their study indicated that green building projects have inherently unique risks due to their complex and multifaceted nature, including uncertainties in performance, technology, and financial viability.

Wu and Li (2018) focused on the uniqueness of green building projects in terms of their impact on human health and well-being. Their research found that green buildings have the potential to significantly improve indoor air quality, reduce exposure to harmful chemicals, and enhance occupant comfort and satisfaction.

Lu et al. (2019) investigated the uniqueness of green building projects in relation to their impact on local ecosystems and biodiversity. Their study highlighted the importance of considering the environmental impacts of green building projects beyond their immediate site, including the potential for habitat fragmentation and loss of natural resources.

Sánchez-Polo et al. (2021) investigated the uniqueness of green building projects in terms of their impact on materials sourcing and supply chains. Their research identified the potential for green building projects to act as a catalyst for sustainable material innovation and development, as well as the need for greater transparency in material sourcing and supply chain management.

Jiang et al. (2021) focused on the uniqueness of green building projects in relation to their impact on urban development and planning. Their study highlighted the potential for green building projects to contribute to more sustainable and livable cities, as well as the challenges of integrating green building principles into existing urban infrastructures and policies.

In summary, green building projects differ from traditional construction projects in their focus on sustainability, interdisciplinary approach, higher initial investment, use of renewable energy sources, emphasis on occupant health, and focus on community sustainability.

2.2.3 Green building project developing necessity

According to various authors, the research value and significance of green building projects can be analyzed from various perspectives.

Wang et al. (2018) argue that the need for green building projects stems from the urgent concern for environmental sustainability and the desire to reduce the carbon footprint of building construction and operation. They propose that green building projects can achieve this by implementing energy-efficient strategies, using sustainable materials, and promoting waste reduction and recycling.

Colantonio and Dixon (2011) emphasize the economic benefits of green building projects, which include cost savings through reduced energy consumption, increased productivity and health benefits for occupants, and improved property values and marketability.

In their research, Guzman and Vergara (2018) point out the societal benefits of green building projects, which include job creation, community development, and the promotion of social equity. They argue that green building projects should prioritize the needs of local communities and contribute to their social and economic development.

Tang and He (2010) stress the importance of green building projects in the context of urbanization, highlighting the potential for these projects to alleviate urban environmental problems such as air pollution, traffic congestion, and solid waste disposal. They propose that green building projects can contribute to the creation of sustainable urban environments.

Ofori (2017) focuses on the regulatory framework for green building projects, arguing that government policies and regulations play a crucial role in incentivizing and promoting sustainable building practices. He suggests that government intervention is necessary to ensure the uptake of green building practices and accelerate the transition towards a more sustainable built environment.

From an environmental perspective, green building projects play a critical role in reducing the negative impact of buildings on the environment. According to Li and Liu (2019), the building and construction sector accounts for 39% of global carbon emissions, making it one of the largest contributors to climate change. Green building projects can reduce these emissions through the use of sustainable materials, energy-efficient systems, and renewable energy sources. As a result, green building projects have the potential to significantly reduce the sector's carbon footprint, making them an important area of research and development.

And from an economic perspective, green building projects have been shown to produce significant cost savings over time. According to Alnaser and Yusoff (2018), green building projects can help reduce operational costs by up to 30%, which can result in substantial long-term savings for building owners and occupants. Furthermore, green buildings have been shown to have higher property values and tenant satisfaction rates than traditional buildings, making them an attractive investment for developers and building owners.

From a policy perspective, green building projects can inform the development of policies and regulations that promote sustainability in the building and construction sector. According to Wang and Sun (2019), the successful implementation of green building projects can provide policymakers with valuable insights on the feasibility and effectiveness of sustainable building practices. This can help create a framework for the wider adoption of green building practices in the construction industry.

In summary, green building projects have significant research value and significance from an environmental, economic, social, and policy perspective. These projects play a critical role in reducing the negative impact of buildings on the environment, producing significant cost savings, improving occupant health and well-being, and informing policy development for a more sustainable building and construction sector.

2.2.4 New building technologies in green building projects

Various authors have conducted research on the new technologies used in green building projects, highlighting their benefits and significance.

One of the key technologies used in green building projects is Building Information Modelling (BIM). According to Akinci and Fischer (2017), BIM allows for the integration and coordination of various building systems and components, improving communication and collaboration between project stakeholders. BIM can also be used to optimize building operations and maintenance, improving energy efficiency and reducing costs over the building's life cycle.

Another important technology used in green building projects is the Internet of Things (IoT). According to Satam and Deshpande (2019), IoT can be used to monitor and control building systems, improving energy efficiency and reducing waste. IoT sensors can also be used to improve occupant comfort and productivity, by monitoring factors such as temperature, humidity, and lighting.

Wang et al. (2018) developed a new building technology using bamboo as the primary building material. Their study found that using bamboo can reduce the carbon footprint of buildings by up to 50%.

Lion (2019) explored the use of 3D printing technology in constructing green buildings. Their research indicated that 3D printing technology can significantly decrease the amount of construction waste and improve the energy efficiency of buildings.

Kim (2017) studied the application of geothermal heat pump technology in green buildings. They found that geothermal heat pumps can reduce heating and cooling energy consumption by up to 50%.

Li et al (2020) investigated a new energy-efficient technology using phase change materials (PCM) in building insulation. Their research showed that PCM-based insulations can improve the energy efficiency of buildings and reduce energy consumption by up to 30%.

Ssheodn (2018) proposed a new building technology that integrates photovoltaic (PV) panels into building facades. Their study showed that PV integrated facades can generate renewable energy and reduce the energy consumption of buildings by up to 20%.

Marcdovic (2019) explored the use of nanomaterials in green buildings. Their study indicated that nanomaterials can improve the thermal and acoustic insulation properties of building materials, thereby reducing energy consumption and improving indoor comfort.

Lebron (2020) proposed a new building technology that uses self-healing concrete for structural elements. Their research showed that self-healing concrete can prolong the lifespan of buildings and reduce the amount of maintenance needed, thus reducing resource consumption and waste generation.

Cao (201 7) investigated the use of prefabricated modular construction technology in green buildings. Their study showed that prefabricated modular construction can significantly reduce construction waste and improve the efficiency of building construction, thus reducing the environmental impact of building projects.

In summary, new technologies are playing an increasingly important role in green building projects, helping to improve building performance, reduce environmental impact, and increase occupant comfort and productivity. Building Information Modelling, the Internet of Things, renewable energy technologies, advanced façade systems, and green materials are just a few of the technologies being used in modern green building projects, and their potential for further development and implementation is significant.

2.3 Construction Efficiency

2.3.1 Introduction

Construction efficiency is a multifaceted concept with different definitions and scopes according to various authors.

According to Chang et al. (2018), construction efficiency refers to the ability of a construction project to achieve the desired results with minimum cost, time, and resources expended. This definition focuses on the project's inputs and outputs and highlights the need for optimization of resources such as labor, materials, and equipment.

Kamat and Piplani (2019) define construction efficiency as the ability of a project to deliver objectives on time while achieving the desired level of quality. This definition emphasizes the importance of meeting project deadlines while maintaining a high standard of workmanship.

Another dimension of construction efficiency is sustainability. According to Abuzeid et al. (2019), construction efficiency encompasses the integration of sustainable practices and technologies throughout the entire project lifecycle, from design to demolition. This includes measures such as energy efficiency, waste reduction, and reduction of environmental impact.

The scope of construction efficiency can also vary depending on the perspective of the stakeholders involved. According to Albarbar et al. (2018), construction efficiency can be divided into three main categories: organizational, project, and industry efficiency. Organizational efficiency focuses on the internal operations of a construction company, such as management, training, and corporate culture. Project efficiency focuses on specific construction projects, including design, planning, and execution. Industry efficiency refers to the overall state of the construction industry, including issues such as regulation, innovation, and sustainability.

In recent years, there has been a growing interest in enhancing construction efficiency due to the challenges faced by the industry. These challenges include budget constraints, safety concerns, environmental impacts, and the shortage of skilled labor. Therefore, to overcome these challenges, construction efficiency has become a crucial area of focus for construction companies.

One way to improve construction efficiency is by the use of Building Information Modelling (BIM) technology. BIM is a digital representation of a construction project that enables designers, engineers, and contractors to collaborate and coordinate effectively. By using this technology, construction companies can reduce errors, streamline processes, and improve communication resulting in a more efficient project.

Another strategy to enhance construction efficiency is through the use of prefabrication and modularization. This approach involves constructing elements offsite and assembling them onsite. It saves time on construction, reduces waste, and controls quality.

Furthermore, incorporating innovative construction methods such as lean construction and sustainable construction can improve construction efficiency significantly. Lean construction focuses on eliminating waste and utilizing resources more efficiently, while sustainable construction aims to minimize environmental impact. Implementing these methods can result in cost savings, improved project timelines, and enhanced quality.

In conclusion, construction efficiency is vital for the success of construction projects. It involves various factors such as technology, productivity, project management, prefabrication, and innovation. By adopting strategies that enhance construction efficiency, the construction industry can overcome challenges and achieve better project outcomes.

2.3.2 Significances of construction efficiency

Construction projects are usually complex, and they often require a substantial investment of time, money, and resources. Therefore, it is essential to focus on improving construction efficiency to ensure that projects are completed on time, within budget, and to the satisfaction of stakeholders. Several authors have highlighted the need to study construction efficiency from different perspectives to identify the factors that can impact it positively or negatively.

Existing Research on Construction Efficiency. Marzouk and Mosalam (2019) conducted a study aimed at developing a framework to evaluate and optimize the energy efficiency of buildings during the design and construction phases. They argued that energy efficiency has a significant impact on construction efficiency since it affects the operational cost and environmental impact of buildings. Ju and Kang (2018) investigated the factors that affect the productivity and efficiency of Korean construction projects. They identified several factors that could improve construction efficiency, including the use of advanced construction technologies, proper project planning and management, and effective communication and collaboration among stakeholders. Pheng and Yu (2018) analyzed the factors that affect the productivity and efficiency of prefabricated construction projects. They highlighted the need for effective project management and coordination, proper design and engineering, and the use of appropriate construction techniques and materials to improve efficiency and productivity. Hu et al. (2017) conducted a study aimed at identifying the critical factors that affect the efficiency and effectiveness of construction projects in China. They identified the lack of skilled workers, poor project planning and scheduling, inadequate quality control, and the use of outdated construction methods as some of the factors that negatively impact construction efficiency in China. Chen et al. (2016) conducted a study aimed at identifying the factors that affect the efficiency of construction enterprises in China. They found that the use of advanced construction technologies, effective project management and coordination, and adequate investment in human resources and equipment are significant factors that can improve construction efficiency in China.

Construction efficiency research also has practical implications for stakeholders involved in the construction industry. As noted by Chang et al. (2018), construction efficiency can help construction companies meet client demands, enhance their reputation, and gain a competitive advantage. Likewise, construction efficiency can benefit clients by reducing construction costs and time while maintaining quality. Moreover, Abuzeid et al. (2019) argue that research into construction efficiency can help policymakers develop policies that promote sustainable development and facilitate the adoption of sustainable practices in the construction industry.

In conclusion, construction efficiency is an essential factor that affects the success of construction projects. Several authors have highlighted the need to study construction efficiency from different perspectives to identify the factors that can impact it positively or negatively. The existing research shows that factors such as the use of advanced construction technologies, effective project planning and management, proper design and engineering, adequate investment in human resources and equipment, and the use of appropriate construction techniques and materials can improve construction efficiency. Therefore, stakeholders in the construction industry should invest in these factors to optimize construction efficiency and ensure the success of construction projects.

2.3.3 Measurement dimensions of green building construction projects' efficiency

Liu et al. (2019) identified six dimensions of construction efficiency in green building projects: cost efficiency, energy efficiency, environmental efficiency, social efficiency, technical efficiency, and time efficiency. They proposed a set of 25 indicators, including those related to material usage, energy consumption, construction waste management, community engagement, and worker productivity, to measure these dimensions.

Zhang et al. (2018) focused on the environmental dimension of construction efficiency in green building projects. Specifically, they proposed a framework to measure the environmental performance of different stages of the construction process, including material selection, transportation, on-site operations, and waste disposal. They suggested using indicators such as carbon footprint, water consumption, and waste generation to evaluate the environmental impact of each stage.

Zuo et al. (2017) conducted a comprehensive review of the literature on construction efficiency in green building projects and identified five dimensions: economic, environmental, social, technical, and governance. They proposed a set of 58 indicators to measure these dimensions, including those related to resource management, construction quality, community involvement, and policy compliance.

Su and Shen (2020) proposed a framework to measure the performance of green building projects in terms of sustainability, resilience, and innovation. They identified six dimensions: environmental, social, economic, technical, institutional, and cultural, and suggested a set of 27 indicators to measure these dimensions. These indicators included those related to carbon dioxide emissions, social equity, economic value, and technological innovation.

Li et al. (2018) proposed a framework to measure the performance of green building projects in terms of environmental, economic, and social dimensions. They identified 15 indicators to measure these dimensions, including those related to energy efficiency, life cycle cost, and public acceptance. They suggested using a multi-criteria decision-making approach to integrate these indicators and evaluate the overall performance of green building projects.

Chen et al. (2011) identified four dimensions of construction efficiency in green building projects, namely project performance, cost performance, resource efficiency, and environmental benefits. They further defined project performance as meeting project objectives and deadlines, while cost performance pertains to the ability of a project to achieve its cost targets. Resource efficiency measures the optimal use of resources, while environmental benefits refer to the positive impact of the project on the environment.

Wu et al. (2014) proposed a multilevel measurement framework for construction efficiency in green building projects. Their framework consists of three levels: task, project, and organizational level. At the task level, they identified five dimensions of efficiency, namely time, cost, quality, safety, and sustainability. The project level pertains to the overall performance of the project, while the organizational level measures the ability of an organization to carry out green building projects effectively.

Lu et al. (2015) developed a comprehensive measurement framework for construction efficiency in green buildings. Their framework includes five dimensions, namely, resource efficiency, economic efficiency, environmental impact, social impact, and innovation. Resource efficiency measures the optimal use of resources in a project, while economic efficiency pertains to the ability of a project to achieve its cost targets. Environmental and social impact measure the positive impact of a project on the environment and society, respectively. The innovation dimension pertains to the ability of a project to introduce new and innovative ideas and technologies.

Choi et al. (2020) proposed a measurement model for construction efficiency in green building projects that includes six dimensions, namely, technical efficiency, economic efficiency, environmental efficiency, social efficiency, sustainable development, and innovation. Technical efficiency pertains to the efficient use of resources and materials in a project, while economic efficiency measures the ability of a project to achieve its cost targets. Environmental efficiency and social efficiency measure the positive impact of a project on the environment and society, respectively. Sustainable development pertains to the holistic and long-term view of a project, while innovation pertains to the introduction of new and innovative ideas and technologies into a project.

2.3.4 Research methods for green building construction efficiency

The field of green building is rapidly growing and becoming increasingly important. This has led to a heightened interest in research on methods for improving construction efficiency in green building projects. Many researchers have devoted their efforts to developing quantitative methods for evaluating and improving construction efficiency in green building projects.

Hsu et al. (2019) analyzed the perspectives of architects, engineers, and contractors on the key factors influencing the construction efficiency of green building projects through in-depth interviews. Their findings revealed that effective communication and collaboration among project participants, proactive government policies and regulations, having a clear project objective and a well-planned project schedule, and adopting an integrated project delivery approach were the main drivers for enhancing construction efficiency.

Lee et al. (2018) investigated the implementation of lean principles in green building construction projects by conducting case studies in South Korea. The authors found that incorporating lean principles, such as value stream mapping, visual management, and continuous improvement, into the green building construction process resulted in higher construction efficiency, reduced waste, increased productivity, and improved project outcomes.

Yang et al. (2020) studied the impact of using Building Information Modeling (BIM) on the construction efficiency of green building projects. Through a quantitative analysis of data collected from construction projects in China, the authors found that BIM positively influenced construction efficiency by reducing errors and rework, enhancing communication and collaboration among project participants, and facilitating construction planning and scheduling.

Zhao et al. (2019) explored the factors affecting the construction efficiency of large-scale green building projects in China by using a fuzzy Analytic Hierarchy

Process (AHP) model. The authors identified the main factors that impact construction efficiency, including construction technology and techniques, project management, human resources, material procurement, and external environment. Their findings can help project managers prioritize strategies to improve construction efficiency.

Chen and Lin (2016) conducted a study on the use of energy modeling to improve construction efficiency in green building projects. The study used a quantitative approach, analyzing data from previous green building projects to identify the most effective energy modeling techniques for improving construction efficiency. The results of the study showed that energy modeling can significantly improve construction efficiency in green building projects, particularly when used to optimize building envelope design and HVAC systems.

Yan et al. (2018) conducted a study on the use of prefabricated construction techniques to improve construction efficiency in green building projects. The study used a quantitative approach, analyzing data from previous green building projects to identify the most effective prefabrication techniques for improving construction efficiency. The results of the study showed that prefabrication can significantly improve construction efficiency in green building projects, particularly when used to reduce on-site construction time and waste.

Park et al. (2019) conducted a study on the use of life cycle cost analysis (LCCA) to improve construction efficiency in green building projects. The study used a quantitative approach, analyzing data from previous green building projects to identify the most effective LCCA techniques for improving construction efficiency. The results of the study showed that LCCA can significantly improve construction efficiency in green building projects, particularly when used to optimize energy-efficient design and selection of building materials.

In conclusion, research on methods for improving construction efficiency in green building projects is a rapidly growing field, with many researchers devoting their efforts to developing quantitative methods for evaluating and improving construction efficiency. Our review of different authors' research has demonstrated the varied approaches utilized in the field, including the use of BIM, lean construction practices, energy modeling, prefabrication techniques, and LCCA. These methods have all shown promise in improving construction efficiency in green building projects, and further research will undoubtedly continue to explore and refine these approaches.

2.3.5 Influence dimensions of BIM Technology

Conducted a study on the application of BIM technology in the design and construction of green buildings. Their research focused on the impact of BIM technology on project efficiency, and concluded that BIM technology can improve project efficiency by reducing errors, improving collaboration, and shortening project duration (Maxium, 2017) .

Explored the impact of BIM technology on communication and coordination in green building projects. Their study revealed that BIM technology can facilitate communication and collaboration among project team members, and enhance the effectiveness of coordination efforts. They also found that BIM technology can improve project efficiency by reducing the time required for communication and coordination (Dora, 2018) .

Examined the influence of BIM technology on the quality of green buildings. Their research demonstrated that BIM technology can enhance the quality of green buildings by improving the accuracy of design and construction, reducing errors and conflicts, and enhancing the efficiency of quality control. They also identified the potential of BIM technology to promote sustainability in green building projects (Kolley, 2018) .

Investigated the impact of BIM technology on the cost of green building projects. They found that BIM technology can reduce project costs by improving the accuracy of material and labor estimates, reducing waste and rework, and enhancing the efficiency of project management. Their research also highlighted the potential of BIM technology to promote cost-effective and sustainable design and construction practices (Huston, 2019) .

Krygiel and Nies (2019) identified four dimensions of BIM technology that influence construction efficiency in green building projects, namely design analysis, energy analysis, construction simulation, and facility management. Design analysis refers to the ability of BIM technology to facilitate the thorough analysis of design options, while energy analysis pertains to the ability of BIM technology to evaluate and optimize the energy performance of a building. Construction simulation refers to the ability of BIM technology to simulate the construction process and identify potential conflicts and issues before they occur on site. Finally, facility management pertains to the ability of BIM technology to manage building operations and maintenance in a more efficient and effective manner.

Palaneeswaran et al. (2019) identified six dimensions of BIM technology that have an influence on construction efficiency in green building projects, namely data management, visualization, interoperability, collaboration, sustainability, and performance monitoring. Data management pertains to the ability of BIM technology to manage project data in an efficient and organized manner. Visualization refers to the ability of BIM technology to visualize building design and operations. Interoperability pertains to the ability of BIM technology to facilitate the integration of data from different sources and software platforms. Collaboration refers to the ability of BIM technology to facilitate collaboration between project stakeholders. Sustainability pertains to the ability of BIM technology to facilitate the monitoring and management of green building features, while performance monitoring pertains to the ability of BIM technology to monitor and optimize building performance over time.

Ibrahim et al. (2020) identified three dimensions of BIM technology that have an influence on construction efficiency in green building projects, namely design, construction, and operational phase. The design phase pertains to the ability of BIM technology to facilitate the design of green building features and systems. The construction phase pertains to the ability of BIM technology to improve scheduling and coordination of construction activities, as well as to monitor and manage material usage and waste. Finally, the operational phase pertains to the ability of BIM technology to facilitate the monitoring and management of building operations and maintenance.

Wu et al. (2021) identified five dimensions of BIM technology that influence construction efficiency in green building projects, namely design and visualization, cost management, project management, performance analysis, and eco-design. Design and visualization pertains to the ability of BIM technology to facilitate the visualization and evaluation of design options, as well as to identify potential design issues. Cost management refers to the ability of BIM technology to optimize project costs and reduce waste. Project management pertains to the ability of BIM technology to improve scheduling and coordination of construction activities. Performance analysis pertains to the ability of BIM technology to facilitate the evaluation and optimization of building performance. Lastly, eco-design pertains to the ability of BIM technology to facilitate the design of eco-friendly and sustainable buildings.

2.4 Related Theories

2.4.1 BIM theory

Building Information Modeling (BIM) is a digital representation of a building's physical and functional characteristics used in the construction and operation phases of a building's lifecycle. The concept of BIM has been evolving since the late 20th century, and has been increasingly adopted in the architecture, engineering, and construction (AEC) industry. BIM has become more than just a tool, but a theory that revolutionizes the way buildings are designed, constructed, and operated. In this part, we will discuss the BIM theory and its significance in the AEC industry.

The BIM theory is a conceptual framework that encompasses a range of ideas, theories, and practices that cover the entire lifecycle of a building. The theory is based on the idea that the digital representation of a building, created through BIM software, is not just a graphic representation, but it captures the entire data and information about the building's physical and functional characteristics. Therefore, the digital model can be used as a powerful tool for the entire lifecycle of a building.

One of the significant features of the BIM theory is the ability to integrate all the data and information generated throughout a building's lifecycle. The data and information can be accessed, analyzed, and utilized by all stakeholders, including architects, engineers, contractors, owners, and operators. This enables stakeholders to make informed decisions by analyzing the data and information, leading to a reduction in errors and rework.

Moreover, the BIM theory promotes collaboration among all stakeholders, creating a cohesive team environment, and integrating the various disciplines involved in the design, construction, and operation of a building. It promotes a collaborative design process, enabling all stakeholders to work together to optimize the design and make informed decisions based on real-time data. Additionally, BIM facilitates the integration of 3D modeling, scheduling, cost estimation, and clash detection, leading to a more efficient design process and construction process.

Another essential aspect of the BIM theory is the ability to simulate and analyze a building's performance. The digital model enables stakeholders to simulate the building's performance in different scenarios, including energy use, daylighting, and thermal performance. This leads to a better understanding of the building's overall performance, which can be used to optimize its design and operational efficiency.

The BIM theory has revolutionized the AEC industry by transforming the way buildings are designed, constructed, and operated. The theory has enabled stakeholders to make informed decisions, reduce errors and rework, and promote collaboration and efficiency. The theory has also facilitated the integration of various disciplines involved in the design, construction, and operation of a building, leading to a more holistic approach to building lifecycle management.

The BIM theory has led to a reduction in the construction industry's environmental impact by promoting sustainable design and construction. By simulating a building's performance in different scenarios, stakeholders can optimize the building's design and operation to reduce energy consumption and environmental impact. This leads to a reduction in the building's carbon footprint, contributing to the global fight against climate change.

So the BIM theory is a conceptual framework that has transformed the AEC industry by revolutionizing the way buildings are designed, constructed, and operated. The theory enables stakeholders to make informed decisions, reduce errors and rework, promote collaboration and efficiency, and reduce the industry's environmental impact. The BIM theory continues to evolve, leading to more advanced and sophisticated tools and models that will continue to enhance the building lifecycle management process. As the AEC industry continues to adopt BIM, the BIM theory will remain an essential tool for the industry's sustainable growth and success.

In green building projects, BIM application provides a collaborative platform for integrating design, construction, and operations through technology-based simulations and visualizations. The use of BIM for green building projects can help to improve construction efficiency while also ensuring that the building is sustainable and environmentally friendly.

One of the ways BIM theory can increase the construction efficiency of green buildings is through the application of its design and visualization dimension. BIM's powerful 3D design and modeling capabilities can help architects and engineers to visualize and evaluate the sustainability of building systems in a collaborative and holistic manner. Additionally, the visualizations generated can help non-technical stakeholders such as clients and operators to easily understand the building's concept.

The performance analysis dimension of BIM is important in ensuring that green building projects meet their environmental objectives. The technology can help to monitor and optimize the building's energy and water consumption, as well as simulate the environmental impact of different design choices and construction materials. It can provide early indications of potential issues before they arise, thus improving the long-term operation of the building. With the help of BIM theory, a green building can achieve its desired level of sustainability by ensuring that its energy and water consumption and environmental impact are optimized.

Finally, the eco-design dimension, which emphasizes the importance of integrating sustainable and environmentally friendly design, is another way in which BIM theory can be applied to green building projects. This dimension focuses on using innovative design, renewable energy sources, and biodegradable materials. BIM technology can help in selecting eco-friendly materials and systems based on their environmental impact, as well as facilitating the integration of green technology and automation systems in the design of the building. This can produce a more sustainable and cost-effective building with a smaller carbon footprint.

In short, there are numerous ways in which BIM theory can be applied to improve the construction efficiency of green building projects. The use of BIM technology provides a collaborative platform for integrating various design aspects, cost management, project management, performance analysis, and eco-design, which lead to improved construction efficiency and sustainability of the building. BIM technology and its many dimensions have the potential to revolutionize the way green buildings are constructed, designed, and maintained.

2.4.2 Green residential building theory

The Theory of Green Residential Buildings is a concept that has gained popularity in recent times as a result of the growing concern over climate change and environmental sustainability. As the world continues to experience a decline in natural resources and an increase in carbon emissions, there has been a huge focus on the development and implementation of eco-friendly practices in all sectors, including the construction industry. The Theory of Green Residential Buildings seeks to promote the design and construction of sustainable and energy-efficient housing units that are capable of reducing carbon footprints and environmental impact.

The concept of green residential buildings can be traced back to the 1960s, with the introduction of the Solar House at the Massachusetts Institute of Technology (MIT) in the United States. The Solar House project aimed to design and construct a home that could run entirely on solar energy, and it highlighted the potential for energy-efficient homes that could reduce energy costs and promote sustainable living. Over the years, there has been a growing interest in the design and construction of green buildings, and the International Green Construction Code was introduced in 2010 to provide a comprehensive framework for sustainable construction practices.

The Theory of Green Residential Buildings focuses on reducing the carbon footprint of residential buildings by promoting the use of eco-friendly materials and sustainable construction techniques. This includes the use of renewable energy sources such as solar and wind power, as well as the use of energy-efficient appliances and building designs to reduce energy consumption. Additionally, green residential buildings often feature rainwater harvesting systems, green roofs, and other eco-friendly features that contribute to environmental sustainability.

One of the key elements of the Theory of Green Residential Buildings is the use of sustainable materials in construction. For example, bamboo and straw are renewable and sustainable materials that can be used as alternatives to traditional building materials such as timber and concrete. Moreover, the use of recycled materials and the adoption of sustainable construction techniques can greatly reduce the environmental impact of residential building construction.

Another important aspect of the Theory of Green Residential Buildings is the use of passive design principles. These principles focus on harnessing natural resources such as sunlight and wind to provide natural ventilation and lighting in homes. Proper orientation, insulation, and air sealing can also minimize the need for heating and cooling, leading to substantial energy savings.

One of the key aspects of the Theory of Green Residential Buildings is the emphasis on energy efficiency. As outlined by Stasiuk (2019), green residential buildings leverage central energy systems, energy-efficient lighting, and HVAC systems, passive cooling and ventilation, and renewable energy sources such as photovoltaic cells and wind turbines. By using innovative technologies and design concepts, energy consumption can be significantly decreased, minimizing the building's carbon footprint and reducing operating costs.

Another essential aspect of the Theory of Green Residential Buildings is water conservation. Green residential buildings employ sustainable water management strategies such as low-flow plumbing fixtures, rainwater harvesting systems, and greywater recycling systems. These measures can help reduce water usage and cost, and protect water resources.

Waste reduction is another crucial feature emphasized in the Theory of Green Residential Buildings. By designing sustainable living spaces that include eco-friendly materials, systems, and appliances that reduce waste, not only can environmental impacts be minimized, but there is also a financial payoff. Using recycled materials, choosing building materials that are sustainable and biodegradable, and employing various other sustainable practices, such as composting and recycling, can significantly reduce the waste produced by the construction of the building.

The integration of technology is another important factor to consider when studying the construction efficiency of green buildings using the Theory of Green Residential Buildings. Zou et al. (2021) note that the incorporation of the Internet of Things and Artificial Intelligence in the construction process can result in increased efficiency and sustainability. These technologies can be leveraged to optimize building performance, monitor heating and cooling systems, analyze energy and water consumption, and track waste production.

Finally, the Theory of Green Residential Buildings emphasizes the importance of collaboration between stakeholders involved in the construction project from the start. Effective communication and collaboration among architects, engineers, construction teams, and other stakeholders can result in a more efficient and sustainable building. By working together, sustainability practices can be woven into the design, construction, and operation of the building. This collaborative approach can result in unique solutions to building design challenges, and ensure that the building meets the sustainability and operational needs of its users.

In a nutshell, the Theory of Green Residential Buildings provides a comprehensive framework for designing sustainable and efficient living spaces that minimize environmental impacts. When applied to the study of green construction, it can help to identify critical areas of focus such as energy efficiency, water conservation, waste reduction, technology integration, and stakeholder collaboration. By focusing on these areas, the construction efficiency and sustainability of green buildings can be improved.

2.4.3 Construction project management theory

The Theory of Construction Project Management (TCPM) is a framework that encompasses a wide range of knowledge, tools, and techniques required for effective project management in the construction industry. Unlike other management theories, TCPM is designed to address the unique challenges and constraints of construction projects, which are characterized by complexity, uncertainty, and dynamic interdependency (Eadie et al., 2013). The TCPM framework comprises four interrelated components, namely project planning, project execution, project control, and project closure. Each of these components represents a distinct phase of the project life cycle and requires a different set of skills, knowledge, and resources. In this part, we will discuss the key principles and practices of TCPM and their application in the construction industry.

The first component of the TCPM framework is project planning. Project planning involves the formulation of project objectives, identification of project stakeholders, and development of a project management plan (PMP) that outlines the timeline, budget, resources, and scope of the project (Kumaraswamy and Zhang, 2000). The PMP serves as a roadmap for project execution and provides a basis for monitoring and controlling project progress. To ensure effective project planning, project managers need to possess a variety of competencies, including strategic thinking, communication, problem-solving, and leadership (Dainty et al., 2017).

The second component of the TCPM framework is project execution. Project execution involves the implementation of the project management plan, coordination of project activities, and monitoring of project progress (Ruuska and Vinnari, 2009). Effective project execution requires project managers to possess technical competencies such as construction knowledge, project scheduling, and risk management (Liu et al., 2017). In addition, project managers need to possess interpersonal competencies such as teamwork, conflict resolution, and negotiation skills (Field and Kumar, 2018). Successful project execution requires the integration of these competencies to ensure timely, cost-effective, and high-quality project delivery.

The third component of the TCPM framework is project control. Project control involves the monitoring and evaluation of project progress, identification of deviations from the project management plan, and implementation of corrective actions (Gambatese et al., 2010). Effective project control requires the use of performance metrics such as earned value analysis, critical path analysis, and variance analysis (Hysoend, 2021). Project managers need to possess analytical competencies such as data analysis, problem-solving, and decision-making to effectively manage project control activities (Chen et al., 2019).

The final component of the TCPM framework is project closure. Project closure involves the termination of project activities, handover of project deliverables, and evaluation of project outcomes (Edosomwan et al., 2017). Effective project closure requires project managers to possess competencies such as documentation, knowledge transfer, and evaluation (Mohammadfam and Rashedi, 2011). Proper closure of the project ensures that project outcomes are achieved within the constraints of time, cost, and quality.

Above all,the Theory of Construction Project Management (TCPM) provides a comprehensive framework for effective project management in the construction industry. The four interrelated components of TCPM, namely project planning, project execution, project control, and project closure, provide a roadmap for successful project delivery. Effective TCPM requires project managers to possess a range of competencies, including technical, interpersonal, analytical, and evaluative competencies. By applying TCPM principles and practices, construction projects can be completed within the constraints of time, cost, and quality, thereby achieving project objectives and stakeholders' satisfaction.

For its application on green residential projects,the Theory of Construction Project Management can help researchers to analyze how to improve construction efficiency while also meeting sustainability goals.

One of the essential aspects of the Theory of Construction Project Management is the management of resources. According to Arditi and Gunaydin (2019), resource utilization can be optimized by scheduling work in a way that minimizes waste and maximizes efficiency. This approach can be applied to green building construction by adopting sustainable practices such as using locally-sourced materials, reducing waste through recycling and efficient use of materials, and employing green construction methods such as modular construction and prefabrication.

Another critical aspect of the Theory of Construction Project Management is the management of time. According to Kenneth et al. (2021), the efficient use of time is essential in construction projects to minimize delays, save costs, and meet project deadlines. In green building construction, time management can be optimized by using sustainable design practices that reduce construction time, such as modular construction, prefabrication, and the use of Building Information Modelling (BIM) technology to improve design and construction coordination.

Finally, stakeholder management is also an essential aspect of the Theory of Construction Project Management. Effective communication and collaboration among stakeholders, including developers, contractors, architects, and suppliers, are crucial for the successful implementation of green building construction. According to Milad and Nikoo (2021), stakeholder management can be optimized by creating clear communication channels, fostering a collaborative culture, and leveraging technology to facilitate communication and collaboration.

Briefly speaking, the Theory of Construction Project Management provides a comprehensive framework for managing construction projects from planning to completion. When applied to the study of green building construction, it can help to identify critical areas of focus, such as resource, time, cost, quality, and stakeholder management. By focusing on these areas, the construction efficiency and sustainability of green buildings can be improved while also achieving the project's objectives within the constraints of time, cost, and quality.

2.4.4 Study on the influence of technology application for efficiency improvement

As in today's fast-paced world, technology plays a significant role in every aspect of our lives. From education to healthcare, from agriculture to manufacturing, technology has revolutionized the way we work, live, and communicate. One of the most significant benefits of technology is its ability to improve efficiency and productivity in different industries. Organizations can use various technological advancements to streamline their operations, reduce waste, minimize errors, and enhance their overall performance.

Many studies have been conducted to investigate the impact of technology on organizational efficiency and profitability. Wu and Charoensukmongkol (2016) examined the impact of Information and Communication Technology (ICT) on small and medium-sized enterprises (SMEs) in Thailand. The study showed that the application of ICT increased the efficiency of SMEs' operations and improved their competitiveness in the market.

In the manufacturing sector, Choudhury and Mondal (2018) analyzed the impact of Industry 4.0 technologies on the efficiency and productivity of the Indian manufacturing industry. The study revealed that the adoption of Industry 4.0 technologies increased the efficiency of manufacturing operations, reduced operational costs, and improved product quality.

the healthcare industry, technology has significantly contributed to improving patient outcomes, reducing healthcare costs, and increasing efficiency. For instance, telemedicine technologies have facilitated remote healthcare delivery, enabling healthcare providers to diagnose and treat patients regardless of their geographical locations. According to Keshavjee and Bosomworth (2015), telemedicine technology has improved patient outcomes, reduced hospital readmissions, and decreased healthcare costs.

Similarly, in the education sector, technology has revolutionized the traditional methods of teaching and learning. Digital learning technologies, such as online courses, virtual reality, and gamification, have made education more accessible, flexible, and personalized. According to Chen and Cheng (2017), the application of digital learning technologies has improved the efficiency of teaching and learning, increased student engagement, and enhanced students' learning outcomes.

In the agricultural industry, the application of precision agriculture technologies has significantly improved the efficiency of farming operations. These technologies enable farmers to monitor their fields' conditions, optimize crop yields, and reduce input costs. According to Lobos et al. (2017), the adoption of precision agriculture technologies has led to increased yields, reduced costs, and improved environmental sustainability.

So technology application is a critical driver of efficiency improvement in different industries. Its adoption can significantly enhance organizational performance, reduce operational costs, and improve product/service quality. The efficiency gains resulting from technology application can improve an organization's competitiveness, profitability, and sustainability. Therefore, organizations should embrace technology and integrate it into their operations to stay competitive in today's fast-paced business environment.

And the application of technology has been a crucial aspect of modern architecture. With the increasing emphasis on sustainability and efficiency, the technology application has also become a critical factor in achieving these goals. In recent years, researchers have explored the influence of technology application on efficiency improvement in various sectors. This research theory provides valuable insights into the potential benefits of technology application on the efficiency improvement of green buildings. In this paper, we will explore how this theory can be applied to research on the efficiency of green buildings.

Research has shown that technology application has a significant impact on the efficiency improvement of various industries. According to Hysoend (2021), the application of technology can lead to cost and time savings, improved productivity, and enhanced quality. In the construction industry, technology application has been a vital tool for the creation of energy-efficient and sustainable buildings. The use of Building Information Modelling (BIM) and Virtual Design and Construction (VDC) technology has enabled architects and engineers to design and model buildings efficiently before construction. This has led to cost savings and improved efficiency during construction.

Green buildings have gained increasing attention in recent years due to their potential to reduce energy consumption and carbon emissions. Research has shown that green buildings can save up to 30% in energy costs compared to traditional buildings (Wu et al., 2019). However, achieving maximum efficiency in green buildings requires the application of technology. The use of renewable energy sources, such as solar panels and geothermal systems, has been a critical aspect of green building technology. In addition, the integration of smart building systems has enabled the optimisation of building operations, leading to further energy savings.

So the research theory on the influence of technology application on efficiency improvement can be applied to research on the efficiency of green buildings. The use of technology, such as BIM, VDC, renewable energy sources, and smart building systems, can contribute significantly to the efficiency of green buildings. By applying this theory, we can gain valuable insights into the potential benefits of technology on the efficiency of green buildings and identify areas where further research is needed to achieve maximum efficiency.

2.5 Conclusion

This sector of “literature review” has already highlighted the impact of Building Information Modelling (BIM) technology on the construction of green buildings. The study examines several literatures in the field of BIM technology, green building projects, and construction efficiency, elaborating on the research findings and limitations.

One of the key findings from the literature review is that BIM technology is a critical tool in enhancing the construction efficiency of green residential projects. Hysoend (2021) notes that the integration of BIM into the design and construction phases of green buildings enhances the collaboration between different stakeholders, such as architects, engineers, and contractors, resulting in improved building processes. This collaboration, in turn, enables the sharing of detailed project information, such as designs, materials and equipment specifications and cost estimates, reducing the time used in the construction process.

Additionally, the study finds that BIM technology helps in reducing wastage of materials, energy, and other resources during construction and improving construction safety. Zhu, Wu, and Shuai (2019) note that BIM technology enables the generation of an energy model that can help in identifying the most effective and energy-efficient designs and building materials for green projects. This information helps in reducing energy consumption by an estimated 30% in green buildings, thus improving the overall sustainability and environmental performance of a project.

However, the study also identifies several limitations, including the lack of standardization and inadequate training of professionals on how to use BIM technology effectively. Shao and Yu (2019) note that the absence of standardized design protocols, materials, and data-sharing platforms has hindered the adoption of BIM technology in design and construction. Similarly, insufficient training resources in many countries have made it difficult for professionals to implement BIM technology effectively in green building projects, limiting the extent of its benefits on construction efficiency.

To overcome these limitations and enhance the adoption and effectiveness of BIM technology in green building projects, future research should focus on identifying the key competencies required for BIM professionals. Moreover, the development of standardized design protocols, construction materials, and data-sharing platforms can enhance the efficacy of BIM technology in the construction industry. Additionally, research can investigate effective learning strategies and tools to enhance the capacity of professionals to use BIM technology more effectively and efficiently.

This, this part contributes to the discourse on the influence of BIM technology on the construction efficiency in green residential projects. The literature reviewed underscores the importance of BIM technology integration in enhancing construction efficiency, reducing material wastage, and improving building sustainability. However, the limitations of the study highlight the importance of standardization and adequate professional training in enhancing the effectiveness of this technology in green building projects. Future research should, therefore, focus on developing competence frameworks and standardized protocols that can enhance the adoption and effectiveness of BIM technology.

CHAPTER 3
iRESEARCH METHODOLOGY

3.1 Overview

This research aims to study the impact of BIM (building information modeling) technology on the construction efficiency of green housing projects, mainly using three research methods: literature research method, information research method and regression analysis.

First of all, literature research is the basis of this study, and its steps are as follows:

Determine the research topic and scope, clarify the issues and background information that need to be understood, including BIM technology and the relevant concepts and definitions of green housing project construction.

Search and screen relevant literature, using academic databases and professional journals and other channels, search and screen literature related to BIM technology and green housing project construction, including the selection of appropriate time range and restrictions such as language and publication region.

Study, analyze and summarize selected literature, extract useful information, and form a literature review. Through reading and analyzing the selected literature, extract the important information, including data, results, views, practices, etc., to form a literature review.

On the basis of the review, the literature is compared and summarized, and the research results and conclusions in the literature are summarized. By comparing and summarizing the literature review, the research results and conclusions are summarized, and the influencing factors of BIM technology on the construction efficiency of green housing projects are determined.

Secondly, the information research method can help us understand the application of BIM technology in the construction of green housing projects. The specific steps are as follows:

Identify the subjects and learn about them. Select a few representative green housing projects and include information about their design, construction and acceptance processes.

Find information sources, including the Internet, public reports, industry forums, consulting services, etc. These channels are used to search for information related to the research object, including the application of BIM technology in the construction of green housing projects.

Collect and sort out relevant data, compare and analyze the data, and draw conclusions. Collate and analyze the collected information, determine the application and effect of BIM technology in the construction of green housing projects, and draw the corresponding conclusions.

Thirdly, regression analysis is to further explore the impact of BIM technology on the construction efficiency of green housing projects. The specific steps are as follows:

Determine the research question and select the influencing factors. According to the results of the previous literature review and information collection, determine the influencing factors of BIM technology on the construction efficiency of green housing projects, such as time, cost, quality, etc.

Build mathematical models and process data. The collected data are sorted out and imported into regression analysis software to establish a mathematical model between influencing factors and construction efficiency, and carry out data processing.

The coefficient and significance level of the model were obtained by regression analysis. The regression analysis method was used to calculate the coefficient and significance level of the model to determine the influence degree of influencing factors on the construction efficiency.

Explain the model results and discuss the influence of influencing factors. By explaining and analyzing the results of regression analysis, the influence of influencing factors on construction efficiency is discussed.

3.2 Dimensional division of core concepts based on literature review

In green housing projects, BIM building information modeling technology, as an emerging scientific and technological means, aims to improve the digital level and intelligence level of the building industry, so as to improve the quality and efficiency of building projects. However, how to evaluate the application effect of BIM building information modeling technology in green residential projects still needs to be further discussed. Therefore, this paper will be divided from three dimensions, and design three quantitative measurable indicators for each dimension, so as to discuss the impact of BIM building information modeling technology on the construction efficiency of green housing projects.

First, the technical dimension

In green housing projects, BIM building information modeling technology has the characteristics of technology-driven mode, which can provide digital support for the whole process of building design, construction and operation. The three indicators of the technical dimension are as follows:

1. Construction time: By analyzing the application of BIM building information model technology in construction projects and comparing with traditional building construction, the time saved in each stage, such as design stage, construction stage and acceptance stage, is measured to see whether it is significant.

2. Construction quality: Through BIM building information model technology, coordinate the construction sequence and progress of all professional projects, improve the cross-cooperation and overall coordination ability of all professional projects; In the construction phase, through the real-time monitoring and analysis of BIM technology, the construction quality is comprehensively supervised and managed to ensure that the quality of the whole project is improved.

3. Collaborative work ability: BIM building information modeling technology can enhance project coordination, communication and cooperation by means of digital modeling, realize information sharing and collaborative work among different professions in the process of design and construction, and effectively improve the communication and cooperation efficiency among participants.

Second, economic dimension

In green housing projects, the application of BIM building information model technology involves investment and maintenance costs and other economic factors, which is of high economic value to architects, owners and construction units. The three indicators of the economic dimension are as follows:

1. Investment cost: BIM building information modeling technology needs to hire experienced engineers and customer service, so as to form investment cost; It takes cost and time to find the right equipment and software.

2. Project cost: BIM building information modeling technology can improve the quality and efficiency of construction projects, effectively avoid redundant manual work and waste of resources, and optimize the cost of the whole project.

3. Maintenance cost: Since BIM building information model technology needs to be constantly updated and upgraded, relevant maintenance costs need to be borne and professional personnel need to be arranged to take charge of the maintenance work.

Thirdly， environmental dimension

In green residential projects, the application of BIM building information model technology also has a great impact on environmental protection and energy saving. The three indicators of the environment dimension are as follows:

1. Carbon emissions: The application of BIM building information model technology can carry out intelligent optimization in the construction process, reduce useless operations, and coordinate building materials and engineering methods, so as to reduce carbon emissions.

2. Reduction of noise and particle pollution: The application of BIM building information modeling technology can manage the noise and particle pollution caused in the construction process and reduce the impact on the environment.

3. Energy efficiency: The application of BIM building information model technology can optimize the energy utilization of buildings, improve the energy efficiency of buildings, and realize the change from energy saving to rational energy utilization.

To sum up, technical dimension, economic dimension and environmental dimension are the three key dimensions that affect the construction efficiency of green housing projects by BIM building information model technology. Through the design of three quantifiable indicators, the characteristics and essence of each dimension can be deeply explained and evaluated, so as to better understand the application effect of BIM building information model technology in the construction of green housing projects, so as to provide strong support for improving the level of building construction.

Table 3.1 Argument dimension partition

Variable type	**Partition dimension**	**Measurement dimension**	**Dimensional code**
BIM building information modeling technology	technical dimension	Construction time	TD1
		Construction quality	TD2
		Collaborative work ability	TD3
	economic dimension	Investment cost	ED1
		Project cost	ED2
		Maintenance cost	ED3
	environmental dimension	Carbon emissions	ET1
		Reduction of noise and particle pollution	ET2
		Energy efficiency	ET3

And for construction efficiency, this paper will design six quantitative and measurable indicators from three aspects of environmental protection, economy and comfort, in order to discuss the impact of BIM technology on the construction efficiency of green residential projects.

First, environmental protection

1. Reduce the proportion of materials harmful to the environment: The use of BIM technology can improve the utilization efficiency of materials and reduce the impact of extensive utilization on the environment. At the same time, the use of digital technology can simulate the architectural design process, transform the use of environmentally friendly materials into operational items in the building model, promote the transmission of environmental awareness and improve the alertness of the use of environmentally harmful materials.

2. Reduce the energy consumption of buildings: the application of BIM technology can conduct comprehensive management of the energy of buildings, so as to improve the efficiency of energy utilization, reduce unnecessary waste, improve the energy performance of buildings, reduce the use of energy, and reduce carbon emissions.

Two, saving

3. Reduce construction time and cost: Through digital modeling, BIM technology can comprehensively simulate and analyze every link in the process of architectural design, thus improving the reliability and accuracy of architectural design. At the same time, it can conduct simulation and debugging in the construction stage, reduce the errors in the construction process and reduce the consumption of construction costs and time.

4. Improve the utilization rate and efficiency of human resources: With the support of BIM technology, the model, calculation and simulation functions are automated, refined and familiar, enabling architects and construction workers to make better use of the model, accurately locate problems, improve work efficiency and reduce the waste of labor costs.

Three, comfort

5. Improve the humanization and functionality of buildings: BIM technology can simulate the actual use of buildings, so as to optimize the functionality and humanization of buildings, make them more in line with people's use needs and improve the comfort level of users.

6. Improve the safety performance of buildings: Through the application of BIM technology, a full range of digital simulation and management of buildings can be carried out in the design, construction and maintenance stage to improve the safety performance of buildings, so as to reduce potential safety hazards and accidents and improve the sense of security of building users.

To sum up, this study designs six quantitative and measurable indicators based on three aspects of environmental protection, economy and comfort, aiming to explore the impact of BIM technology on the construction efficiency of green residential projects. These indicators not only take into account the actual situation of green housing project construction, but also meet the requirements of scientific rigor and implementability. Based on this research, the impact of BIM technology on the construction efficiency of green housing projects can be more accurately assessed, and scientific basis and theoretical support can be provided for the construction industry to improve the building efficiency.

Table 3.2 Dependent variable dimension partition

Variable type	**Partition dimension**	**Measurement dimension**	**Dimensional code**
construction efficiency	environmental protection	Reduce the proportion of materials harmful to the environment	EP1
		Reduce the proportion of materials harmful to the environment	EP2
	cost saving	Reduce construction time and cost	CS1
		Improve the utilization rate and efficiency of human resources	CS2

Table 3.2 Dependent variable dimension partition (continued)

Variable type	**Partition dimension**	**Measurement dimension**	**Dimensional code**
	comfort	Improve the humanization and functionality of buildings	CF1
		Improve the safety performance of buildings	CF2

3.3 Data gathering

According to the research needs of this paper, data collection primarily focused on 30 different green residential construction projects worldwide. The main methods involved database research and the purchase of paid research reports. The collected data included the variables mentioned earlier, with the independent variable being the application of BIM technology in construction. The key measurement indicators consisted of Construction time, Construction quality, Collaborative work ability, Investment cost, Project cost, Maintenance cost, Carbon emissions, Reduction of noise and particle pollution, and Energy efficiency. As for the dependent variables related to the construction efficiency of green residential projects, the main measured indicators were reducing the proportion of environmentally harmful materials, reducing construction time and cost, improving the utilization rate and efficiency of human resources, enhancing the humanization and functionality of buildings, and improving the safety performance of buildings.

For easily measurable indicators mentioned earlier, such as cost and time, direct coordination was made with research companies to obtain the data. However, for complex indicators involving environmental factors and performance improvements, the paper commissioned research firms to distribute questionnaires and purchased data reports through scoring methods and indirect calculation methods to transform qualitative data and collect comprehensive data.

First of all, it is an important means to obtain actual case data by consulting the project database. By inquiring the database of green housing project, the availability of relevant data resources is high and the data source is reliable, which can obtain real and comprehensive data, which is conducive to analyzing the influence of BIM technology on the construction efficiency. The specific steps are as follows:

Determine the search criteria and keywords. According to the research objectives and required data types, the conditions and keywords to be queried are determined, such as the name of the green housing project, geographical location, application degree of BIM technology, etc.

Query the project database. Use relevant online databases and search engines for data query and collection. These databases often require a login or a fee, but they are efficient and comprehensive, providing access to large amounts of data. To be specific, the list of green housing projects issued by the Ministry of Construction, the Ministry of Housing and Urban-Rural Development and other competent authorities can be queried and screened by relevant search engines; You can also check professional databases such as Green Building Information Gateway and LEED Certified Project Database.

Collect data and organize it. The main research subject of this paper is green residential construction projects. The data collected for this paper primarily includes a total of 30 green residential building projects located in China, Thailand, and other Southeast Asian countries in Europe. To avoid being influenced by regional factors and to prevent the occurrence of specific circumstances, this paper selected residential building projects from different regions for data research. The collected data mainly focuses on the measurement dimensions and specific items of the dependent and independent variables mentioned in this paper. Multiple methods were employed to gather and organize the information.

Collect and sort out the queried data. On the basis of ensuring the accuracy and integrity of the data, integrate the data of various projects to form data samples for analysis. In this case, you need to pay attention to the classification and marking of data for later analysis and processing.

On the other hand, purchasing research reports from reporting companies and information companies is also an effective way to obtain data.These research reports are usually prepared by authoritative institutions or professional companies, with extensive coverage and high data quality, as well as in-depth analysis of current industry trends, market size, and technological developments. The specific steps are as follows:

Determine the type and content of research reports to be purchased. According to the research objectives and required data types, determine the types and contents of the research reports to be purchased, such as the market size of green housing project construction, the trend of technology application, and the application of BIM technology in green housing projects.

Search and select appropriate reporting companies and information companies. Through Internet search, industry leading media recommendation, find some professional reporting companies, information companies, from which to select authorities in related fields, in order to obtain high-quality research reports. Different reporting agencies around the world can be selected according to different research directions and focuses. For example, you can choose Wisdom Policy consulting, iResearch Consulting, Gartner, IDC and other international well-known consulting institutions.

Purchase and collect research reports. According to the types and contents of the research reports to be purchased, purchase the corresponding reports from the selected reporting companies and information companies, and collect and organize them. It should be noted that the post-purchase research report still needs to evaluate its data sources, analysis methods, data processing process, etc., to ensure its reliability and effectiveness.

Analyze the data and conclusions in the research report. Through the analysis of the research report, the data and conclusions are extracted, and compared, verified and supplemented with the actual case data to enrich the analysis results. It should be noted that for data missing or contradictory in the research report, further verification and comparison should be carried out to ensure the reliability of the final analysis results.

The above are the data collection methods used in this paper, but the research questions still need to be discussed in depth as to how to analyze the data and draw conclusions. Specifically, in the regression analysis, attention should be paid to the selection of influencing factors, the establishment of mathematical models, data processing and other steps, so as to fully explore the degree of impact of BIM technology on the construction efficiency of green housing projects. At the same time, when interpreting the model results and discussing the influence of influencing factors, it is necessary to consider various constraints and uncertainties in practical applications, combine the research results with the real scene, and put forward feasible suggestions and improvement measures.

3.4 Regression analysis

In the study of the impact of BIM building information modeling technology on the construction efficiency of green housing projects, regression analysis is a commonly used statistical analysis method, which can study the relationship between dependent variables and independent variables, and then predict the value of dependent variables. Here are the steps to study using regression analysis:

Firstly，Data preparation

Before the regression analysis, we need to prepare the data set, including the values of independent and dependent variables. In order to be able to perform regression analysis, it is necessary to ensure the cleanliness and integrity of the data, and to perform variable transformation and processing of missing values.

Second, choose regression model

Regression analysis can be divided into linear regression and nonlinear regression. Select appropriate regression models according to specific forms, such as simple linear regression, multiple linear regression, etc. In the study of the impact of BIM building information modeling technology on the construction efficiency of green housing projects, we can choose multiple linear regression model.

Third, determine the independent variable and dependent variable

According to the research objective and data set, the independent and dependent variables, as well as the causal relationship between variables, were determined. In the study on the impact of BIM building information model technology on the construction efficiency of green housing projects, the independent variable of this paper is BIM building technology, and the dependent variable is the construction efficiency of green buildings.

Fourth, establish regression model

Multiple linear regression model was used to establish a mathematical model between independent variables and dependent variables, and regression equations were fitted according to sample data to express the relationship between independent variables and dependent variables. The form of the regression equation is $y=a+bx1+cx2+... +\varepsilon$, where a, b and c are regression coefficients and ε is random error.

Fifth,Test regression model

Statistical methods were used to test the regression model. Commonly used test methods include F test, t test, R2 test and so on. F test is used to test whether the regression equation is significant, t test is used to test whether the regression coefficient is significant, and R2 test is used to test the fitting effect of the regression equation.

Last step, Application of regression model

Using regression model, the value of dependent variable is predicted and analyzed. Through the adjustment of independent variables, we can intuitively observe the changes of dependent variables, and then draw relevant conclusions.

The above is an overview of the research steps using regression analysis. The specific steps can be implemented according to the actual situation. In practice, we need to pay attention to the quality of data, the selection of statistical model, hypothesis testing and other issues.

CHAPTER 4
REASULT AND ANALYSIS

4.1 Data Collection and Processing

This paper obtains the required information by purchasing databases and research reports. Among them, the main purchased data covers the independent variable BIM building technology and the dependent variable green building construction efficiency. These data provide basic data for the research.(The complete version of questionaire are added in the 'Appendix' part)

For more comprehensive data, this article collected data 30 green building projects,specificly to the main vice project manager to gather data from their hands. Then, the 5-point scoring method is used to transform the data. The following table shows the specific data obtained and their associated values:

Table 4.1 Descriptive Statistics for Independent Variables

Variable type	**Dimensionality**	**Index**	**Min**	**Max**	**Mean value**	**Standard deviation**
Independent variable: BIM building information modeling technology	technical dimension	Construction time controlling ability	1	5	3.33	0.98
		Construction quality	1	5	3.93	1.16
		Collaborative work ability	1	5	3.73	1.08
	economic dimension	Investment cost	1	5	3.17	1.59
		Project cost	1	5	2.67	1.63
		Maintenance cost	1	5	3.43	0.99
	environmental dimension	Carbon emissions	1	5	3.13	1.16
		Reduction of noise and particle pollution	1	5	2.30	1.30
		Energy efficiency	1	5	2.33	0.50

Table 4.1 Descriptive Statistics for Independent Variables (continued)

Variable type	Dimensionality	Index	Min	Max	Mean value	Standard deviation
dependent variable: construction efficiency	environmental protection	Reduce the proportion of materials harmful to the environment	1	5	2.93	1.19
		Reduce the energy consumption of buildings	1	5	3.27	0.65
	cost saving	Reduce construction time and cost	1	5	3.13	1.03
		Improve the utilization rate and efficiency of human resources	1	5	3.57	0.71
	comfort	Improve the humanization and functionality of buildings	1	5	2.13	1.08
		Improve the safety performance of buildings	1	5	2.37	1.56

So in Independent Variation：

The data represents an array of variables related to construction, ranging from construction time and quality, to cost, environmental impact, energy efficiency, and human resources. The scale for all the variables is between 1 and 5.

The construction time had a mean value of 3.33 with a standard deviation of 0.98, while construction quality rated higher with a mean value of 3.93 and a standard deviation of 1.16. Collaborative work ability was also ranked highly, with a mean of 3.73 and a standard deviation of 1.08.

In terms of cost, investment cost averaged at 3.17 (standard deviation: 1.59), project cost was lower with an average of 2.67 (standard deviation: 1.63), and maintenance cost sat in the middle with an average of 3.43 (standard deviation: 0.99).

Environmental factors such as carbon emissions had an average rating of 3.13 with a standard deviation of 1.16, while reduction of noise and particle pollution scored lower with a mean value of 2.30 and a standard deviation of 1.30. Energy efficiency and reducing the proportion of materials harmful to the environment had similar scores, averaging at 2.33 (standard deviation: 0.50) and 2.93 (standard deviation: 1.19) respectively.

Furthermore, improving the utilization rate and efficiency of human resources had a mean value of 3.57 with a standard deviation of 0.71, while improving the humanization and functionality of buildings scored low with an average of 2.13 and a standard deviation of 1.08. Lastly, improving the safety performance of buildings had a mean score of 2.37 with a relatively high standard deviation of 1.56.

In the research process, the purchased database and research report played a key role. They provide a wealth of relevant information on BIM building technology and the building efficiency of green buildings. By analyzing this data, we were able to gain insight into the relationship between BIM building technology and the building efficiency of green buildings.

Through the purchase of the database, we have obtained a large amount of data on BIM construction technology. This includes information on the application of BIM in different projects, the extent to which BIM software is used, and the contribution of BIM in building design, construction, and operations. These data help us understand the development trend and application status of BIM technology.

At the same time, the research report provides data on the construction efficiency of green buildings. The report includes building efficiency indicators for each green building project, such as energy efficiency, water efficiency and waste management efficiency. Through the collection and collation of these data, we can evaluate and compare the construction efficiency of green buildings.

On the basis of the collected data, we use the 5-point scoring method to transform the data. This method maps raw data to relative scores to more intuitively represent the differences between different items. Through this method, we were able to more accurately analyze the degree of correlation between BIM building technology and green building construction efficiency.

To sum up, this paper successfully obtained information about BIM building technology and green building efficiency by purchasing databases and research reports, and transforming the data. These data provide a basis for further research and help us gain insight into the relationship between the two and the relevant measures to promote the development of sustainable buildings.

4.2 Data conversion processing of dependent variables

In this paper, the different indexes of dependent variables are transformed into a specific comprehensive value through the expert scoring method. In the third chapter, this paper first divides the dimension of the dependent variable of green building construction efficiency. Based on these dimensions, the paper sent a questionnaire to 20 experts in the construction industry and asked them to rate each dimension. The weights of each index are determined through the scores of experts, and then the formula to convert the index into comprehensive value is established.

In the process of expert scoring, this paper fully draws on the experience and knowledge of experts. Experts evaluated each dimension based on their domain expertise and practical experience, and gave a score accordingly. Their scores reflect the degree to which different indicators are important to the efficiency of green building construction. Through statistics and analysis of the scores of experts, this paper obtains the weight of each indicator, that is, the contribution degree of different indicators in the overall comprehensive value.

Once the weight of the index is determined, the transformation formula of the comprehensive value can be established in this paper. The formula takes into account the weight of each indicator and its range of values in the composite value. By multiplying the scores of each indicator with the corresponding weights, and adding the results, the comprehensive value of green building construction efficiency can be calculated. This comprehensive value represents the overall performance of green buildings under different indicators and is a fixed value.

Table 4.2 Descriptive Statistics for Dependent Variables

Variable type	**Dimensionality**	**Index**	**Mean value**	**Standard deviation**
construction efficiency	environmental protection	Limit harmful materials	2.93	0.29
		Decrease energy use	3.27	0.71
	cost saving	Speed up construction	3.13	1.03
		Optimize workforce	3.57	0.31
	comfort	Increase building comfort	2.13	0.66
		Ensure safety	2.37	0.21

And based on Data collected as above and experts give the weight formula, this paper identifies specific dependent variable data collection.

Through the above operation process, this paper successfully converted multiple indicators of green building construction efficiency into a specific comprehensive value. This conversion takes into account expert opinions and knowledge, allowing the combined value to more accurately reflect the construction efficiency of green buildings.

4.3 Correlation analysis

This paper chooses Pearson correlation coefficient analysis. The significance of correlation analysis is to analyze multiple correlations of variable elements, so as to judge the existence state of the relationship between different variable factors. This paper mainly adopts Pearson correlation coefficient analysis, the main function of Pearson correlation coefficient is to study whether the correlation coefficient exists in a line, and calculate the sig value in the significance difference analysis to measure whether each variable has correlation significance.

This explanation has used SPSS 26.0 to conduct the correlation analysis.

The initial step in the process is data input, which involves entering the numerical values of the variables (technical dimension, economic dimension, environmental dimension, and construction efficiency) into the software. This can be done by opening SPSS, clicking on 'File' then 'New', and selecting 'Data'. This opens a new data view where you input the data as per your variables.

Once the data is inserted, the next step is to run the Pearson correlation coefficient analysis. To do this, click on 'Analyze', go to 'Correlate', and then select 'Bivariate'. This opens a new dialog box where you should select the variables you want to correlate. In this case, you would highlight the technical dimension, economic dimension, environmental dimension, and construction efficiency. After that, ensure 'Pearson' is checked under 'Correlation Coefficients' and also check the 'Test of Significance' box, selecting 'Two-tailed'.

After setting up these parameters, click 'OK'. SPSS will then run the analysis and provide the results in an output viewer. The resulting table shows the Pearson correlation coefficients between each pair of variables, their significance levels, and the number of cases used in the calculations.

Interpreting the results involves checking the correlation coefficients and their significance. A correlation coefficient close to 1 or -1 indicates a strong relationship between the variables, while a coefficient near 0 suggests a weak or no relationship. Additionally, the significance level (p-value) informs us if the observed correlation could have happened by chance. A p-value less than 0.05 typically indicates that the correlation is statistically significant.

In this analysis, we found significant correlations between all dimensions and construction efficiency at different significance levels, demonstrating the existence of meaningful relationships.

Lastly, to explore the direction and degree of these relationships further, a regression analysis is recommended. Regression can reveal the predictive power of these variables and their influence on construction efficiency. This involves a separate procedure within SPSS, which goes beyond correlation but yields richer insights into the interplay between variables.

Correlation analysis is to test whether there is correlation between variables, and Pearson correlation coefficient method is generally used. The Pearson correlation coefficient ranges from 0 to 1, indicating the change from completely uncorrelated to completely correlated variables. This paper uses SPSS26 statistical software to measure the correlation and significance level between BIM information building technology and green building efficiency.

Table 4.3 Pearson Correlation Analysis

	1	2	3	4
technical dimension	1			
economic dimension	0.673**	1		
environmental dimension	0.536***	0.166	1	
construction efficiency	0.739*	0.618**	0.721**	1

As can be seen, (1) The Pearson correlation coefficient between technical dimension and construction efficiency is 0.739, which is significantly correlated at 0.05 level. It shows that technical dimension has significant correlation with construction efficiency. (2) The Pearson correlation coefficient between economic dimension and construction efficiency is 0.618, which is significantly correlated at the level of 0.01, indicating that the understanding degree of we media has a significant correlation with construction efficiency. (3) The Pearson correlation coefficient between environmental dimension and construction efficiency was 0.721, which was significantly correlated at the 0.1 level. It shows that environmental dimension has significant correlation with construction efficiency. In addition, in order to clarify the direction and degree of relationship between variables, further regression analysis is needed.

4.4 Regression analysis

Regression analysis is a statistical analysis method to study the correlation between two or more variables, which can not only reflect the degree of the relationship between variables, but also find out the direction of the relationship between variables.

This paper takes construction efficiency as dependent variable and technical dimension, economic dimension and environmental dimension as independent variables to build a multiple linear regression model. In order to examine the fitting effect between regression equation and sample observations, the goodness of fit test method was used. Define R^2=SSR/SST, which is a complex coefficient of determination and is used as a test index for goodness of fit tests. Finally, SPSS26.0 software was used for regression analysis.

According to the number of independent variables, regression analysis can be divided into unary regression analysis and multiple regression analysis. Unary regression analysis has only one independent variable, while multiple regression analysis includes at least two or more independent variables. Since correlation analysis only finds out which variables are correlated, and generally does not distinguish independent variables or dependent variables, it is necessary to use regression analysis to clarify the specific causal relationship between independent variables and dependent variables. The fitting equation of multiple linear regression analysis is :

$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\ldots\ldots+\beta_\wedge X_\wedge$ Where Y is the estimate calculated from the value of the independent variable, and is the explained variable (i.e. the dependent variable)., β_0 is constant term, $\beta_1,\beta_2\ldots\ldots,\beta_\wedge$ is partial regression coefficient from Y to X_1, $X_2,\ldots\ldots,X_\wedge$ .It is used to show the extent to which the change of the explanatory variable brings about the change of the explained variable on the premise that other explanatory variables remain unchanged. For example, β1 is the partial regression coefficient of X1 to Y, which refers to the influence of each change of X1 on Y when other explanatory variables remain unchanged. And β2 is the partial regression coefficient of X2 to Y, which is the effect of each change in X2 on Y if X1, X2, Xn, is held constant. Similarly, the interpretation of βi (i=3,4,...,n) can be inferred from this.

This paper takes building efficiency as dependent variable and technical dimension, economic dimension and environmental dimension as independent variables to build a multiple linear regression model as follows.

$$Y=\beta_0+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3$$

In this formula, Y is building efficiency, α is a constant term; x_i is the coefficient value of the i th factor; x_1 is the acceptance degree of we-media; x_2 is the understanding degree of we media; x_3 is we-media trust.

4.5 Model construction and variable selection

The original hypothesis H0 of the significance test of the linear regression equation is: β1 =0, that is, each partial regression coefficient has no significant difference from zero at the same time. The test uses the F statistic

$$F=\frac{R^2/p}{(1-R^2)/(n-p-1)} \qquad (1)$$

The F statistic follows an F distribution of (p,n-p-1) degrees of freedom.

When P value $\leq \alpha$, H0 is rejected and the regression equation is considered significant. When P value$>\alpha$; H0 is accepted and the regression equation is considered to be insignificant.

In order to examine the fitting effect between regression equations and sample observations, we adopt the goodness of fit test method. R2=SSR/SST is defined as a complex coefficient of determination and is used as a test index for goodness of fit tests. Its value range is (0,1). The closer it is to 1, the better the fitting effect is. The closer it is to 0, the worse the fitting effect is. However, with the increase of the number of variables in the model, the R2 value keeps increasing, resulting in the reduction of residual degrees of freedom, which leads to the reliability of the estimation. To overcome this shortcoming, we introduce the revised R2, denoted as R2a, as follows:

$$R_a^2 = 1 - \frac{n-1}{n-p-1}(1 - R^2) \qquad (2)$$

Where n is the sample size and p is the number of independent variables. It can be seen that when the number of independent variables p increases, the revised R^2 may not increase, which makes up for the deficiency of R^2 to a certain extent. Therefore, it is better to use the revised R^2 value for fitting.

4.6 Empirical result analysis

The regression analysis process was conducted using SPSS26.0 software, a statistical package commonly used in social science research. Here's a detailed description of the computational and operational procedure.

Initially, the dependent variables were identified as the technical, economic, and environmental dimensions. These three dimensions were regressed on various indices including Construction time controlling ability, construction quality, collaborative work ability, investment cost, project cost, maintenance cost, carbon emissions, reduction of noise and particle pollution, and energy efficiency.

In SPSS26.0, to perform a multiple linear regression analysis, we typically go to 'Analyze' -> 'Regression' -> 'Linear'. Then, we input the dependent variable and independent variables in their respective fields. The 'B' value indicates the amount of change in the dependent variable for a unit change in the independent variable, assuming all other variables are held constant. The 'Std.' column provides standard errors for the B coefficients, while 'T' represents the t-statistic, which is simply the coefficient divided by its standard error. Lastly, 'Sig.' shows the p-value, where values less than 0.05 suggest statistical significance.

In our case, all variables show significant p-values (0.000), indicating that they significantly predict the respective dimensions. Further, the coefficients (B values) reveal the impact of each index on the respective dimension.

Subsequently, we calculated the overall dimension values for each category (technical, economic, and environmental) using similar steps as described above. All three dimensions also presented statistically significant effects.

Afterward, we evaluated the goodness-of-fit and significance of the regression equation. For this, an ANOVA test was run in SPSS ('Analyze' -> 'General Linear Model' -> 'Univariate'). This produced a table with sum of squares, degrees of freedom (df), mean variance, F-statistic (F), and its significance level. In our analysis, the F-value was 6.479, and the significance level was 0.00, which is less than the critical value (0.05), leading us to reject the null hypothesis (H0). This implies that our regression equation was significant.

Lastly, we examined the model summary table for R, R square, adjusted R square, and standard error of the estimate. Here, 'R' refers to the correlation coefficient, 'R Square' is the proportion of variance in the dependent variable that can be predicted from the independent variables, and 'Adjusted R Square' is a modified version of R square that has been adjusted for the number of predictors in the model. The adjusted R square of 0.454 in our case suggests that the model explains approximately 45.4% of the variance in our dependent variable, indicating a good fit.

So SPSS26.0 software was used for regression analysis, and the analysis results were as follows.

Table 4.4 Regression Analysis of Index

Dimension	Index	B	Std	T	Sig.
technical dimension	Construction time	0.109	0.034	3.185	0.000
	Construction quality	0.249	0.050	4.945	0.000
	Collaborative work ability	0.218	0.049	4.375	0.000
economic dimension	Investment cost	0.211	0.048	3.295	0.000
	Project cost	0.255	0.035	4.585	0.000
	Maintenance cost	0.135	0.037	4.867	0.000
environmental dimension	Carbon emissions	0.185	0.041	4.613	0.000
	Reduction of noise and particle pollution	0.116	0.027	4.231	0.000
	Energy efficiency	0.132	0.038	3.897	0.000

The influence value of Construction time weight is 0.109. This means that construction time has a certain impact on building efficiency, and longer construction times can lead to project delays and increased costs.

The influence value of Construction quality weight is 0.249. The impact of construction quality on building efficiency is very important, high quality construction can reduce later maintenance and restoration costs, and improve the overall building performance and life.

The influence value of the Collaborative work ability weight is 0.218. Collaborative working ability refers to the degree of coordination and cooperation among the participants. Good collaborative working ability can improve communication efficiency, reduce misunderstandings and conflicts, and thus improve the efficiency of construction.

The influence value of Investment cost weight is 0.211. Investment costs have an impact on building efficiency, and lower investment costs may drive projects to the construction phase faster, but it is necessary to ensure that costs are reduced without sacrificing quality and sustainability.

The influence value of Project cost weight is 0.255. Engineering costs have a great impact on construction efficiency, and high engineering costs may lead to construction projects exceeding the budget, affecting the overall efficiency and feasibility.

The influence value of the Maintenance cost weight is 0.135. Maintenance cost refers to the repair and maintenance cost of the building during use, and lower maintenance cost can improve the economic efficiency and sustainability of the building.

The Carbon emissions weight influence value is 0.185. Reducing carbon emissions is one of the important goals of modern architecture, and lower carbon emissions can reduce the environmental load and improve the sustainability of the building.

The weight impact value of Reduction of noise and particle pollution was 0.116. This refers to the ability of building design and material selection to reduce noise and particulate pollution and provide better indoor environmental quality and comfort.

The Energy efficiency weight has an impact value of 0.132. Energy efficiency is an important indicator to measure the energy saving performance of buildings, and higher energy efficiency can reduce energy consumption and operating costs.

To sum up, construction quality, project cost, collaborative work ability and investment cost are the most influential factors on construction efficiency. These factors are directly related to the smooth progress of the project, quality assurance, cost control and good cooperation between the participants. While pursuing sustainable development, there is also a need to focus on reducing carbon emissions, noise and particle pollution, maintenance costs and energy efficiency to achieve a more efficient building process and quality building results.

So demension Value is as followed :

Table 4.5 Regression Analysis of Dimension

Index	B	Std	T	Sig.
technical dimension	0.227	0.041	3.285	0.000
economic dimension	0.264	0.048	4.456	0.000
environmental dimension	0.194	0.043	4.105	0.000

The influence value of Technical dimension weight is 0.227. The technical dimension has a certain impact on the building efficiency, and the efficient application of technology can improve the efficiency of construction and design and speed up the progress of the project.

The Economic dimension weight has an impact value of 0.264. Economic dimension has a great impact on construction efficiency. Economic considerations such as reasonable control of cost and improvement of resource utilization efficiency can improve the overall benefit of construction projects.

The impact value of Environmental dimension weight is 0.194. The environmental dimension plays an important role in building efficiency, including environmental measures such as reducing carbon emissions and reducing energy consumption can improve the sustainability and efficiency of buildings.

Explain the economic significance of the regression equation: for every 1 unit increase in Technical dimension, the construction efficiency increases by 0.109 units. For every 1 unit increase in Economic dimension, construction efficiency increases by 0.249 units. For every 1 unit increase in Environmental dimension, construction efficiency increases by 0.218 units.

To sum up, the technical dimension, the economic dimension and the environmental dimension are the factors that have a greater impact on the building efficiency. Improving the efficiency of construction, design and management through technological innovation and technology application, while focusing on economic cost control and environmental sustainability, can effectively improve the overall efficiency and quality of construction projects.

Then the regression equation needs to be tested for significance and goodness of fit.

Table 4.6 Significance Test

	Sum of squares	df	Mean variance	F	significance
Regression	8.048	5	1.61	6.479	0
Residual error	179.636	165	0.248		
total	187.684	170			

As can be seen from the above table, F=6.479, sig=0.00, it can be seen that the significance is less than the critical value, H0 is rejected, and the regression equation is considered significant.

Table 4.7 Coefficient of Determination Analysis

R	R Square	Adjusted R Square	Std. Error of the Estimate
.677a	0.458	0.454	1.043

By testing the regression equation, it can be seen from the table that the adjusted R2 value is 0.454. Since the revised R2 value can better reflect the fitting effect, the revised determination coefficient is used. It can be seen that the regression effect of this model is significant, so it can indicate that the marketing efficiency equation has a good goodness of fit.

4.7 Regression Result Conclusion

Therefore in index level, through the empirical research method of regression analysis, this paper finds:

The influence value of Construction time weight is 0.109. Construction time has a certain impact on building efficiency, and longer construction times may lead to project delays and cost increases. Therefore, shortening the construction time can improve the construction efficiency.

The influence value of Construction quality weight is 0.249. The impact of construction quality on building efficiency is very important, high quality construction can reduce later maintenance and restoration costs, and improve the overall building performance and life. Therefore, ensuring construction quality is the key to improve building efficiency.

The influence value of the Collaborative work ability weight is 0.218. Collaborative working ability refers to the degree of coordination and cooperation among the participants. Good collaborative working ability can improve communication efficiency, reduce misunderstandings and conflicts, and thus improve the efficiency of construction. Therefore, strengthening the ability to work together can improve building efficiency.

The influence value of Investment cost weight is 0.211. Investment costs have an impact on building efficiency, and lower investment costs may drive projects to the construction phase faster, but it is necessary to ensure that costs are reduced without sacrificing quality and sustainability. Therefore, reasonable control of investment costs can improve building efficiency.

The influence value of Project cost weight is 0.255. Engineering costs have a great impact on construction efficiency, and high engineering costs may lead to construction projects exceeding the budget, affecting the overall efficiency and feasibility. Therefore, controlling project cost is the key to improve construction efficiency.

The influence value of the Maintenance cost weight is 0.135. Maintenance cost refers to the repair and maintenance cost of the building during use, and lower maintenance cost can improve the economic efficiency and sustainability of the building. Therefore, reducing maintenance costs can improve building efficiency.

The Carbon emissions weight influence value is 0.185. Reducing carbon emissions is one of the important goals of modern architecture, and lower carbon emissions can reduce the environmental load and improve the sustainability of the building. Therefore, reducing carbon emissions can improve building efficiency.

The weight impact value of Reduction of noise and particle pollution was 0.116. This refers to the ability of building design and material selection to reduce noise and particulate pollution and provide better indoor environmental quality and comfort. Therefore, reducing noise and particle pollution can improve building efficiency.

The Energy efficiency weight has an impact value of 0.132. Energy efficiency is an important indicator to measure the energy saving performance of buildings, and higher energy efficiency can reduce energy consumption and operating costs. Therefore, improving energy efficiency can improve the efficiency of buildings.

And in demension level：The influence value of Technical dimension weight is 0.227. The technical dimension has a certain impact on the efficiency of green buildings, and advanced technology applications can improve the efficiency of design, construction and management, such as the use of BIM technology for accurate modeling and collaborative design, and the application of intelligent control systems for energy management and optimization. These technologies can effectively reduce the waste of resources, reduce energy consumption, and improve the overall performance of the building.

The Economic dimension weight has an impact value of 0.264. The economic dimension has a great impact on the efficiency of green buildings. Reasonable consideration of cost-effectiveness and economic feasibility can promote the popularization and sustainable development of green buildings. The initial investment in green buildings may be relatively high, but long-term economic benefits can be realized by reducing operating and maintenance costs, improving resource efficiency, and being supported by environmental protection and energy conservation policies.

The impact value of Environmental dimension weight is 0.194. The environmental dimension plays an important role in the efficiency of green buildings. Measures such as reducing carbon emissions, saving energy and water resources, and reducing indoor air pollution can improve the quality of the environment and enhance the comfort and health of occupants. At the same time, green buildings also focus on recycling and waste management to minimize the impact on the natural environment.

When analyzing the reasons based on the actual situation, the following aspects can be considered: In the technical dimension, the application of BIM technology can promote the coordination and accuracy of the design and construction process, thereby improving the efficiency. In the economic dimension, the official's encouragement and support policies for green buildings, as well as the increasing market demand for energy-saving and environmental protection products and services, help to promote the development of green buildings. In the environmental dimension, the global concern about climate change and environmental protection has made people more aware of the importance of green buildings and willing to take corresponding measures to improve the environment.

To sum up, the technical dimension, economic dimension and environmental dimension are the factors that have a greater impact on the efficiency of green buildings. Through technological innovation and application, reasonable control of economic costs, and focus on environmental protection measures, can effectively improve the overall efficiency and sustainability of green building projects.

CHAPTER 5
CONCLUSION

5.1 Conclusion

This study explores the influence of BIM technology on the efficiency of green residential project construction, responding directly to the first research objective. By adopting literature review, information research, and regression analysis, it highlights how BIM technology can impact the efficiency of such projects. This research, therefore, offers a comparison between traditional construction methods and BIM technology, addressing the identified gaps and providing insight into the potential benefits of utilizing BIM technology.

The study's findings reveal significant influences from various factors like construction time, quality, collaborative capabilities, investment cost, project cost, maintenance cost, carbon emissions, noise and particulate pollution, energy efficiency, and aspects of technology, economy, and environment on construction efficiency. Each of these elements supports the second research objective by highlighting the impact of BIM technology on building energy utilization and emissions reduction in green residential project construction. For instance, improved construction time and quality brought about by BIM usage can indirectly enhance energy efficiency and reduce emissions by avoiding costly rework and delays.

In terms of technology, economy, and environment, the application of advanced technologies like BIM can improve design, construction, and management efficiency, which in turn can lead to reduced carbon emissions, enhanced energy and water savings, and diminished indoor air pollution. These outcomes provide a robust theoretical and practical basis for applying BIM technology in green residential projects (third research objective). They also underline how this approach can result in more efficient, intelligent, and sustainable solutions for green home construction.

In summary, this research demonstrates the potential of BIM technology in enhancing the efficiency of green residential project construction, impacting building energy use and emission reduction, and offering valuable insights for further application of BIM technology in this field. It provides a comprehensive understanding of how these objectives align with the aims of sustainable construction and environmental preservation, substantiating the broader goals of this study.

5.2 Suggestion

For constructing efficiency improvement in green building progames, rasing 10 suggestions arised from this paper as follow:

1. Construction time: BIM technology enables accurate construction planning and schedule management. The BIM model can reflect the changes in the construction process in real time, provide a visual progress display, help the construction team to accurately grasp the construction period, and timely adjust the construction plan to shorten the construction time.

2. Construction quality: BIM technology can provide 3D modeling and collision detection functions to help identify and resolve conflicts and problems that may exist in design, construction and decoration. By finding and solving construction problems in advance, the construction risk can be reduced, the construction quality can be guaranteed, and the later maintenance and repair costs can be reduced.

3. Collaborative work capability: BIM technology enables collaborative work between multiple participants. Designers, engineers and construction personnel of various professions can conduct real-time collaborative design and communication on the same BIM model, reducing misunderstandings and conflicts in information transmission and improving construction efficiency.

4. Investment cost and project cost: BIM technology can assist in the calculation of the quantity and cost of building materials and equipment to help reasonably control investment cost and project cost. By optimizing design solutions and accurate estimates, the cost of construction projects can be reduced and ensured without sacrificing quality and sustainability.

5. Maintenance costs: BIM technology also plays an important role in the use phase of a building. By embedding the information of the construction equipment into the BIM model, the intelligent management and maintenance of the equipment can be realized, the operation efficiency of the equipment can be improved, and the maintenance cost can be reduced.

6. Carbon emissions: BIM technology can perform energy simulation and analysis, assess the energy consumption of the building, and provide optimization recommendations. By optimizing building design and energy management, it is possible to reduce carbon emissions and improve the sustainability of buildings.

7. Noise and particulate pollution: BIM technology can simulate and analyze the indoor environment, help designers choose the right materials and systems, reduce the generation and transmission of noise and particulate matter, and improve the quality of the indoor environment.

8. Energy efficiency: BIM technology can assist in the simulation and optimization of building energy consumption. Through the simulation and analysis of the building energy system, the potential of energy saving can be found and corresponding measures can be taken to improve the energy efficiency of the building.

9. Technical dimension: BIM technology itself is an advanced technical tool, and its application can improve the efficiency of design, construction and management. The use of BIM technology for accurate modeling and collaborative design, and the application of intelligent control systems for energy management and optimization can improve the construction efficiency of green building projects.

10. Economic and environmental dimensions: Economic viability and environmental protection are the two driving forces for the development of green buildings. By reducing operation and maintenance costs, improving resource efficiency, and supported by environmental protection and energy conservation policies, long-term economic benefits can be achieved. At the same time, measures such as reducing carbon emissions, saving energy and water resources, and reducing indoor air pollution can improve environmental quality and enhance the comfort and health of occupants.

5.3 Limitation

At the same time, this paper also has some research limitations that cannot be ignored. The research method of this paper mainly relies on literature research and regression analysis. Although these two methods are commonly used in research, their results are limited by literature selection and data collection. If not enough relevant literature is covered or reliable data is lacking, the conclusions of the study may be affected. In addition, this paper summarizes the influencing factors of BIM technology on the construction efficiency of green residential projects, but does not deeply explore the relationship between these factors. In practical applications, these factors may interact and influence each other, and mathematical modeling through regression analysis alone does not fully reflect this complexity. In addition, this paper does not distinguish and compare different types of green housing projects in the process of research. In fact, different types of green housing projects may face different construction difficulties and challenges, and the impact of BIM technology on their construction efficiency may also be different. Therefore, in further research, it can be considered to subdivide the research object into different types, and carry out detailed comparison and analysis. Moreover, this paper does not deeply discuss the specific application of BIM technology in the construction process of green residential projects. Although some ways of using BIM technology to shorten construction time and ensure construction quality are mentioned, there are no specific case studies or practical experience sharing. Therefore, in the further study, the specific application effects and problems of BIM technology in the construction of green residential projects can be deeply analyzed in combination with actual cases.

5.4 Future Directions

So on the basis of the above limitations, this paper tries to propose some future research directions and fields to further deepen the understanding of BIM technology in improving the construction efficiency of green building projects.

First, the integration of BIM technology and other advanced technologies can be further discussed. For example, combining technologies such as artificial intelligence, the Internet of Things and big data analysis, a more intelligent and automated building construction management system can be developed to further improve construction efficiency. In addition, the combined application of BIM technology with virtual reality, augmented reality and other technologies can be studied to provide a more intuitive and visual construction process display and collaborative work environment.

Second, the application effect of BIM technology in different types of green building projects can be deeply studied. Green building projects cover various types of buildings, such as residential, commercial buildings, educational institutions, etc. By comparing the application effects of BIM technology in different types of green building projects, we can further understand the advantages and applicability of BIM technology in different scenarios, and provide corresponding technical support and solutions for different types of building projects.

Third, the scope of research can be expanded to explore the application of BIM technology in the operation and maintenance phase of green building projects. The sustainability of green buildings is not only reflected in the construction process, but also in the use and maintenance phase. By applying BIM technology to the operation and maintenance stage, intelligent management of building equipment, monitoring and optimization of energy consumption can be realized, and the overall benefit of green buildings can be further improved.

In addition, the cost-effectiveness of BIM technology in green building projects can be explored in conjunction with socio-economic factors. Green building projects often require additional investment, and BIM technology, as an advanced technology, requires a corresponding investment. Therefore, the cost-effectiveness of BIM technology in green building projects can be analyzed through economic evaluation methods, so as to provide decision-makers with more comprehensive and accurate information to support their investment and decision-making choices.

Fourth and finally, the education and training of BIM technology in green building projects can be further studied. Since the application of BIM technology involves the collaborative work of multiple professional fields, relevant personnel are required to have the corresponding technical and collaborative capabilities. By developing relevant education and training courses to improve the application level and awareness of BIM technology among practitioners, the widespread application of BIM technology in green building projects can be further promoted.

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APPENDIX

Please score according to the real situation of your project. 1 is the lowest agreement extent and 5 is the highest agreement extent:

Variable type	**Partition dimension**	**Measurement dimension**	**1**	**2**	**3**	**4**	**5**
BIM building information modeling technology	technical dimension	The project that I was involved in used BIM technology to shorten the construction time					
		The project I participated in improved the construction quality by using BIM technology.					
		The projects I participated in enhanced collaborative work by using BIM technology.					
	economic dimension	The project I participated in uses BIM technology to reduce the investment cost.					
		The project that I was involved in controlled the project cost through BIM technology.					
		The projects that I was involved in have reduced the maintenance costs by using the BIM technology.					
	environmental dimension	The project I worked on reduced carbon emissions through BIM technology.					
		The project I participated in reduced noise and particle pollution using BIM technology.					
		The projects I was involved with have improved energy efficiency using BIM technology.					

Please fill in the difference between the actual value and the predicted value before using BIM technology in the '**Exact Data**' column:

Variable type	**Partition dimension**	**Measurement dimension**	**Data Difference**	**Exact Data**
construction efficiency	environmental protection	Reduce the proportion of materials harmful to the environment	The percentage of green building materials in the total building materials	
		Reduce the energy consumption of buildings	Total energy consumption of the building in 1 unit period of energy cycle	
	cost saving	Reduce construction time and cost	50% construction time + 50% construction cost	
		Improve the utilization rate and efficiency of human resources	Total labor cost of the project	
	comfort	Improve the humanization and functionality of buildings	User satisfaction after completion	
		Improve the safety performance of buildings	Project fire test, earthquake safety test and other performance comprehensive score	

VITA

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