Comparison of green building rating systems and the usage of smart materials using BIM

Comparația sistemelor de evaluare a construcților verzi și utilizarea materialelor inteligente cu BIM

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DOI: 10.37789/rjce.2025.16.1.2

Abstract
The escalating importance of green building practices in tackling environmental challenges necessitates innovative solutions, particularly emphasizing resource conservation, energy efficiency, and occupant well-being. Building Information Modeling (BIM) has emerged as a promising tool to enhance efficiency in construction projects. This sophisticated digital platform enables real-time collaboration and visualization of the construction process. This study aims to explore the potential of BIM in promoting sustainability within smaller-scale building projects. The utilization of Building Information Modeling (BIM) presents a significant opportunity to enhance the design of green buildings. By integrating BIM with building rating systems, architects can ensure that their structures meet the necessary standards for green certification. The study focuses on assessing the impact of Building Information Modeling (BIM) on resource efficiency, energy performance, waste reduction, and cooperative decision-making in small-scale green buildings. Results indicate a positive correlation between BIM adoption and various aspects of sustainability, including early-stage design optimization, energy efficiency analysis, material selection, life cycle assessment, waste reduction, and prefabrication using LEED (Leadership in Energy and Environmental Design), BREEAM **(**Building Research Establishment Environmental Assessment Method**)**. The findings underscore the significance of incorporating BIM into smaller-scale construction projects to promote eco-friendly practices and achieve sustainable outcomes. By leveraging BIM of smart materials, architects and construction professionals can enhance resource efficiency, improve energy performance, reduce waste generation, and facilitate collaborative decision-making throughout the project lifecycle.

Keywords: Building Information Modeling (BIM); LEED (Leadership in Energy and Environmental Design); BREEAM **(**Building Research Establishment Environmental Assessment Method); Green building; Smart Materials;

The article was received on 19.11.2024, accepted on 24.02.2025 and published on 14.03.2025

1.Introduction

In recent years, there has been a heightened global focus on combating climate change and advancing sustainable development, leading to increased efforts to adopt environmentally responsible practices across various industries [1-5]. Recognizing the construction industry's substantial resource consumption and contribution to construction and demolition waste, there has been a notable shift towards promoting more sustainable building techniques within the sector. Green building, which integrates energy efficiency, resource conservation, and occupant well-being, has emerged as a pivotal solution to address environmental concerns[6]. With a primary focus on minimizing the building's impact on the environment, research indicates significant advantages of green buildings compared to conventional structures. Studies suggest that green buildings may achieve remarkable reductions in energy consumption by up to 50%, water consumption by 40%, and carbon emissions by 35% [7]. These statistics underscore the substantial potential of green building practices in mitigating the adverse effects of construction on the natural environment.

Building Information Modeling (BIM) has revolutionized the stages of planning, designing, and construction. BIM is an intelligent digital platform that facilitates real-time collaboration among stakeholders, allowing them to share information and visualize the construction process in three dimensions [7]. This transformation has propelled BIM into an essential technology for enhancing the efficiency of building projects, minimizing construction errors, and enhancing building functionality [8]. As the benefits of Building Information Modeling (BIM) in streamlining construction processes became increasingly evident, researchers and professionals in the field recognized the potential of combining BIM with environmentally friendly building practices [9]. Integrating the data-rich environment of BIM with sustainability analysis has shown promise in facilitating early-stage design decisions that result in energy-efficient designs and ecologically responsible material choices [10]. This synergy between BIM and sustainability analysis offers opportunities to optimize building designs for environmental performance from the outset of the project.

The construction industry's significant impact on global energy, raw material, water, land consumption, and solid waste production has propelled efforts to improve environmental sustainability, given its substantial contributions to these areas: 40% of global energy consumption, 30% of global raw material consumption, 25% of global water consumption, 12% of global land consumption, and 25% of global solid waste production [11]. Sustainable building practices have emerged as a solution to mitigate these environmental impacts [12]. Sustainable buildings aim to reduce water and energy consumption while maintaining occupants' well-being. However, designing sustainable buildings poses challenges due to the need for multidisciplinary design teams to address diverse environmental, social, and economic needs [13]. Building rating systems for sustainable buildings are developed to evaluate the environmental performance of structures [14] and promote sustainability across their planning, construction, and operation phases [15]. A variety of building rating systems have been developed to assess and highlight a building's sustainable performance [16]. These rating tools measure environmental performance, ensuring that optimal sustainable practices are incorporated into the design, construction, and operation of the building [17]. Building rating systems play a crucial role in guiding decision-making processes for sustainable buildings [18]. To ensure resource efficiency throughout a building's lifecycle, it is imperative to integrate these rating tools into the design process [19]. This integration facilitates the adoption of sustainable design principles from the outset, thereby optimizing the building's overall environmental performance.

This research provides valuable insights into the potential of Building Information Modeling (BIM) to enhance resource efficiency, energy performance, waste reduction, and collaborative decision-making in small construction projects through the analysis of real-world case studies and practical applications. These findings open up new avenues for achieving sustainable outcomes in smart materials construction endeavors. By offering innovative results and evidence-based suggestions, this research aims to equip stakeholders with practical tools to foster a greener and more ecologically responsible built environment, thus contributing to the advancement of sustainable practices in the construction sector. The hypothesis outlined in Figure 1 illustrates the anticipated impact of implementing BIM on sustainability in small construction projects, guiding further investigation into this important area.

- **S1:** Early-stage design optimization is significantly associated with the implementation of Building Information Modeling (BIM) in smart material projects. This hypothesis proposes that the utilization of BIM in smart construction is likely to have a notable positive impact on early-stage design optimization. In essence, BIM is expected to contribute to enhanced design processes and outcomes in smart material projects.
- **S2**: Energy efficiency and performance analysis are significantly correlated with the implementation of BIM in smart material projects. This hypothesis suggests that the integration of BIM in smart material construction projects is anticipated to be closely linked to improved energy efficiency and the capability to conduct more comprehensive performance analysis. It implies that BIM can play a crucial role in augmenting the energy performance of buildings in smart material construction endeavors.
- **S3:** Utilizing Building Information Modeling (BIM) in smart materials projects exhibits a strong correlation with material selection and life cycle assessment. This hypothesis suggests that the adoption of BIM likely enhances material selection procedures and enables comprehensive life cycle assessments in small construction projects. It is anticipated that BIM facilitates making more informed decisions regarding materials and their long-term sustainability.
- **S4:** The application of BIM in smart materials projects is strongly associated with waste reduction and prefabrication. This hypothesis suggests a noticeable reduction in construction waste and an increased utilization of prefabricated components when BIM is implemented in smart materials projects. It indicates that BIM can support the adoption of

environmentally responsible and more efficient building methods, including the use of smart materials.

The hypotheses of the study are as follows:

- S1 or H1: Early-stage design optimization is positively influenced by the implementation of Building Information Modeling (BIM) in small construction projects.
- S2 or H2: Implementation of BIM in small construction projects leads to improved energy efficiency and performance analysis.
- S3 or H3: The utilization of BIM in small construction projects correlates with enhanced material selection procedures and comprehensive life cycle assessment.
- S4 or H4: Integration of BIM in small construction projects is associated with reduced waste generation and increased adoption of prefabrication methods.

These hypotheses serve as the guiding principles for exploring the relationship between BIM implementation and various aspects of sustainability in small-scale construction projects.

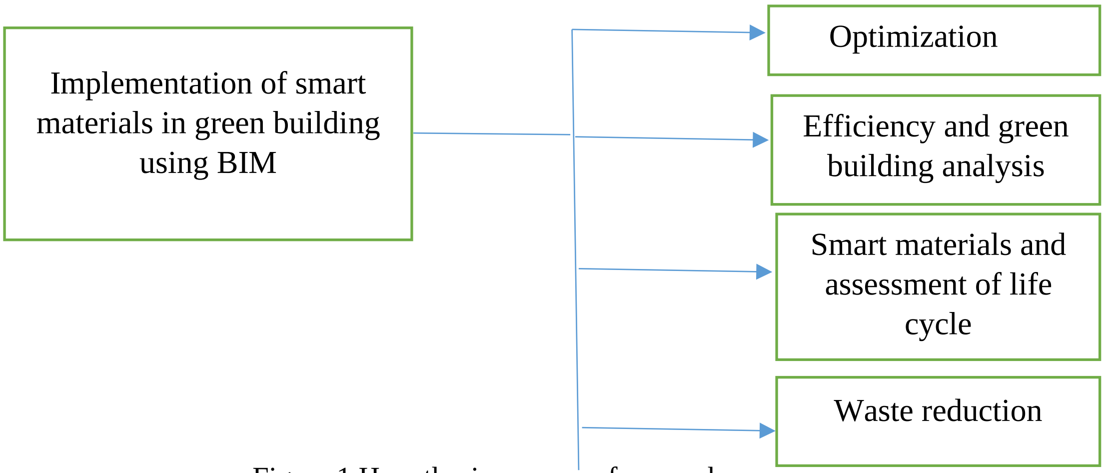


Figure 1 Hypothesis process of research

2. Building Assessment Tools

Building rating systems and assessment tools are commonly utilized to evaluate a building's environmental performance. These include well-known systems such as the Green Building Index (GBI), Green RE, Green Mark, Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), among others. BREEAM, established in the UK in 1990, and LEED, created by the US Green Building Council (USGBC) in 1998, are prominent examples. Additionally, systems like Green Mark (Singapore), GBI, and Green RE (Malaysia) cater to specific regional needs. These rating systems aim to assess a building's sustainability performance by considering factors such as energy efficiency, resource conservation, indoor environmental quality, and overall environmental impact.Building rating tools are systems or frameworks used to evaluate and assess the sustainability and environmental performance of buildings. These tools provide a standardized method for measuring various aspects of a building's sustainability, including energy efficiency, water usage, materials selection, indoor air quality, and overall environmental impact. Some of the most widely used building rating tools include:

- **Leadership in Energy and Environmental Design (LEED)**: Developed by the U.S. Green Building Council (USGBC), LEED is one of the most recognized green building certification programs globally. It assesses buildings based on criteria such as energy efficiency, water conservation, materials selection, and indoor environmental quality.
- **Building Research Establishment Environmental Assessment Method (BREEAM)**: Originating in the UK, BREEAM evaluates the sustainability performance of buildings across various categories, including energy, water, materials, pollution, and management processes. It provides ratings ranging from Pass to Outstanding based on the overall performance of the building.
- **Green Building Index (GBI)**: GBI is a green rating tool developed specifically for Malaysia. It evaluates buildings based on criteria such as energy efficiency, indoor environmental quality, sustainable site planning, and materials selection

3. Building Information Modelling (BIM)

In recent years, Building Information Modelling (BIM) has emerged as a valuable tool for addressing sustainability challenges. BIM provides a platform for visualizing both the physical and functional aspects of a building, offering a wealth of data, including geometric and semantic information [23]. This data can be integrated into BIM models to propose sustainable measures during the design phase, facilitating more accurate environmental performance analysis and sustainability assessments. Integration with BIM enables collaborative information sharing among stakeholders involved in construction projects. Additionally, BIM is often combined with Life Cycle Assessment (LCA) to enhance a building's sustainability assessment. Automated tools utilizing BIM and LCA can calculate energy consumption and carbon emissions, aiding decision-makers in optimizing building performance. Research has demonstrated that integrating BIM and LCA enables designers to select more environmentally friendly materials and products. While LCA typically focuses on comparing the environmental impacts of two sustainable buildings rather than certification or meeting minimum sustainable requirements, this study shifts its focus to reviewing research that employs BIM to assist in the certification process and compliance with minimum sustainable requirements from building rating tools.

4. Methods

The research methodology commences with an extensive literature review. This step involves a meticulous analysis of existing literature on green building practices and the utilization of Building Information Modeling (BIM) in smart materials construction projects. Case studies and best practices are also examined. The aim of this process is to identify key elements and variables that facilitate the effective implementation of BIM in smart materials, environmentally sustainable building projects. By reviewing relevant literature, the study builds a robust knowledge base, enabling a comprehensive understanding of past successes and the fundamental principles guiding the adoption of BIM in green building initiatives.

Following the literature analysis, the study progresses to the quantitative investigation phase. In this phase, the study examines real smart materials building projects that utilize BIM for green building techniques. Data from these projects are analyzed using statistical methods, with a focus on key sustainability metrics such as waste reduction, energy performance, resource efficiency, and collaborative decision-making. Specifically tailored to small construction projects, the analysis aims to offer empirical evidence of the positive impact of BIM implementation on these sustainability aspects. Through this analysis, the study aims to demonstrate practically how BIM can effectively support sustainability initiatives in smaller-scale building projects. Structural Equation Modelling (SEM), a highly developed statistical technique, is used in the research study's final stage. SEM enables us to thoroughly examine the hypotheses and explore the intricate relationships between different elements that affect the application of BIM for green building in small projects. We can comprehend the complex relationships between BIM adoption and sustainability outcomes better thanks to this advanced analysis. Through the application of SEM, the research can furnish industry participants with comprehensive and empirically-supported perspectives, ultimately aiding in the creation of sustainable construction methodologies customized to the particular circumstances of small-scale building undertakings.

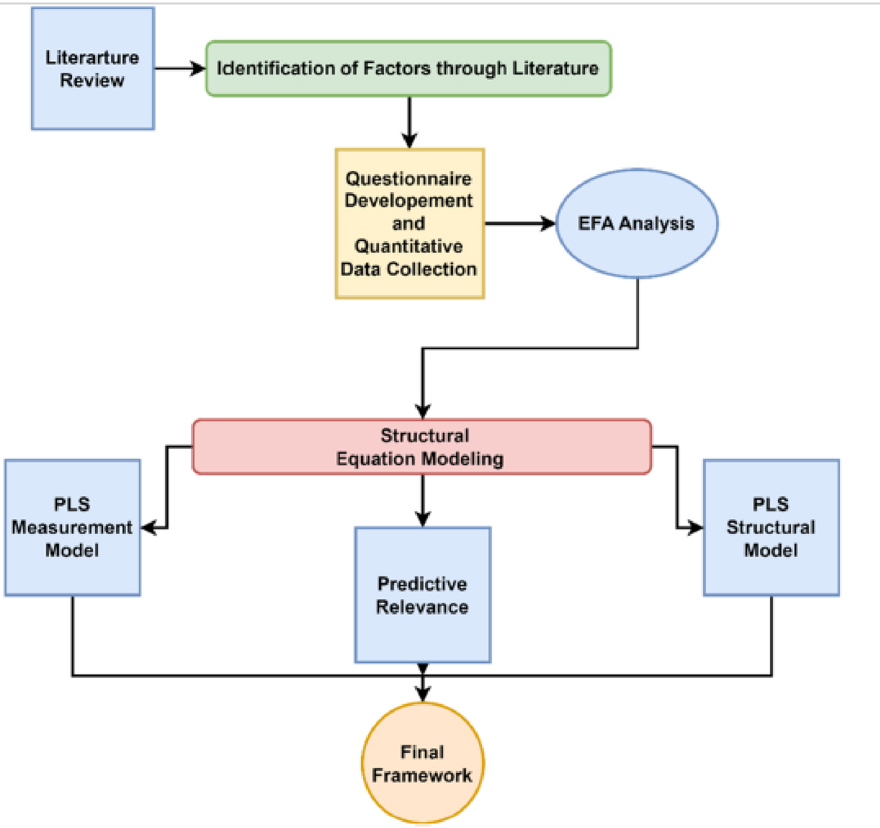


Figure 2 Research methodology

4.1 Smart materials with BIM

The integration of smart materials with Building Information Modeling (BIM) presents exciting opportunities for enhancing the sustainability and efficiency of construction projects. Smart materials are those designed with embedded sensors, actuators, or other advanced technologies that enable them to respond to external stimuli or perform specific functions. When combined with BIM, these materials can offer several benefits:

- **Real-time Monitoring and Control**: Smart materials equipped with sensors can provide real-time data on various parameters such as temperature, moisture levels, and structural integrity. This data can be integrated into the BIM model, allowing project stakeholders to monitor the performance of materials throughout the construction process and even during the operational phase of the building.
- **Optimized Building Performance**: By integrating smart materials into the BIM model, designers can simulate different scenarios and assess the impact of material choices on the building's performance. For example, BIM can be used to analyze the energy efficiency of a building by simulating the behavior of smart materials that regulate temperature or lighting based on environmental conditions.
- **Improved Decision-making**: BIM provides a collaborative platform for project stakeholders to visualize and analyze building designs. By incorporating smart materials into the BIM model, stakeholders can make more informed decisions regarding material selection, construction methods, and building systems, leading to improved sustainability and efficiency.
- **Enhanced Maintenance and Lifecycle Management**: Smart materials can facilitate predictive maintenance strategies by providing early warning signs of potential issues such as structural degradation or equipment malfunction. When integrated with BIM, this data can be used to create digital twins of buildings, allowing for better lifecycle management and optimization of maintenance schedules.
- **Reduced Environmental Impact**: Smart materials with energy-saving features or sustainable properties can contribute to reducing the environmental footprint of construction projects. By incorporating these materials into the BIM model, designers can assess their impact on energy consumption, material usage, and overall sustainability performance.

5. Data collection

The integration between BIM and simulation software enables more accurate environmental performance analysis and better-informed decision-making throughout the design process. Moreover, the interoperability between BIM and simulation tools streamlines workflows and reduces the time and effort required to perform sustainability assessments. As a result, the combination of BIM with LEED and simulation software offers a powerful framework for designing and constructing sustainable buildings. However, it is worth noting that while LEED may be one of the most frequently integrated building rating systems with BIM, other systems such as BREEAM and Green Star also have established integrations with BIM, albeit to varying extents. Therefore, the choice of building rating system and associated BIM integration tools may depend on project-specific requirements and regional preferences.

Table 2

Overview of BIM and building rating tools

References	Group	Code	Description
[1]	Optimization of Early-stage	BIM-EO1	BIM effectively manages resources to minimize waste and promote environmentally friendly alternatives.
[2]		BIM-EO2	BIM facilitates informed sustainable design decisions, promoting the development of greener building designs
[3]		BIM-EO3	BIM enhances collaboration, making it more accessible and facilitating the attainment of sustainable objectives.
[4]		BIM-EO4	BIM enables sustainable site planning by optimizing building orientation to maximize energy efficiency.
[5,6]	Efficiency and green building analysis	BIM-EA1	BIM enables energy analysis and facilitates the identification of energy-saving methods.
[7]		BIM-EA2	BIM-guided designs result in lower greenhouse gas emissions, thereby reducing the building's carbon footprint.
[8,9]		BIM-EA3	The integration of BIM for enhanced energy efficiency contributes to a more favorable green image for the building.
[10,11]	Smart materials and assessment of life cycle	BIM-MS1	BIM aids in making environmentally responsible choices by prioritizing materials with low embodied carbon and high percentages of recycled content.
[13-15]		BIM-MS2	Using BIM to select materials with low levels of volatile organic compounds (VOCs) is an effective method for enhancing indoor air quality within buildings.
[16-18]		BIM-MS3	Selecting long-lasting materials is crucial to minimize the need for maintenance and replacement, thereby

References	Group	Code	Description
			optimizing resource utilization and reducing environmental impact.
[19]	Smart materials and assessment of life cycle	BIM-WB1	BIM can reduce waste in building and demolition by maximizing the utilization of each material's potential quantity.
[20,21]		BIM-WB2	A more precise estimate facilitated by BIM helps reduce surplus material and minimizes the amount of construction and demolition waste generated during the construction process.
[22]		BIM-WB3	Prefabrication integrated with BIM streamlines operations, leading to construction completed in less time.

6. Data analysis

6.1 EFA analysis

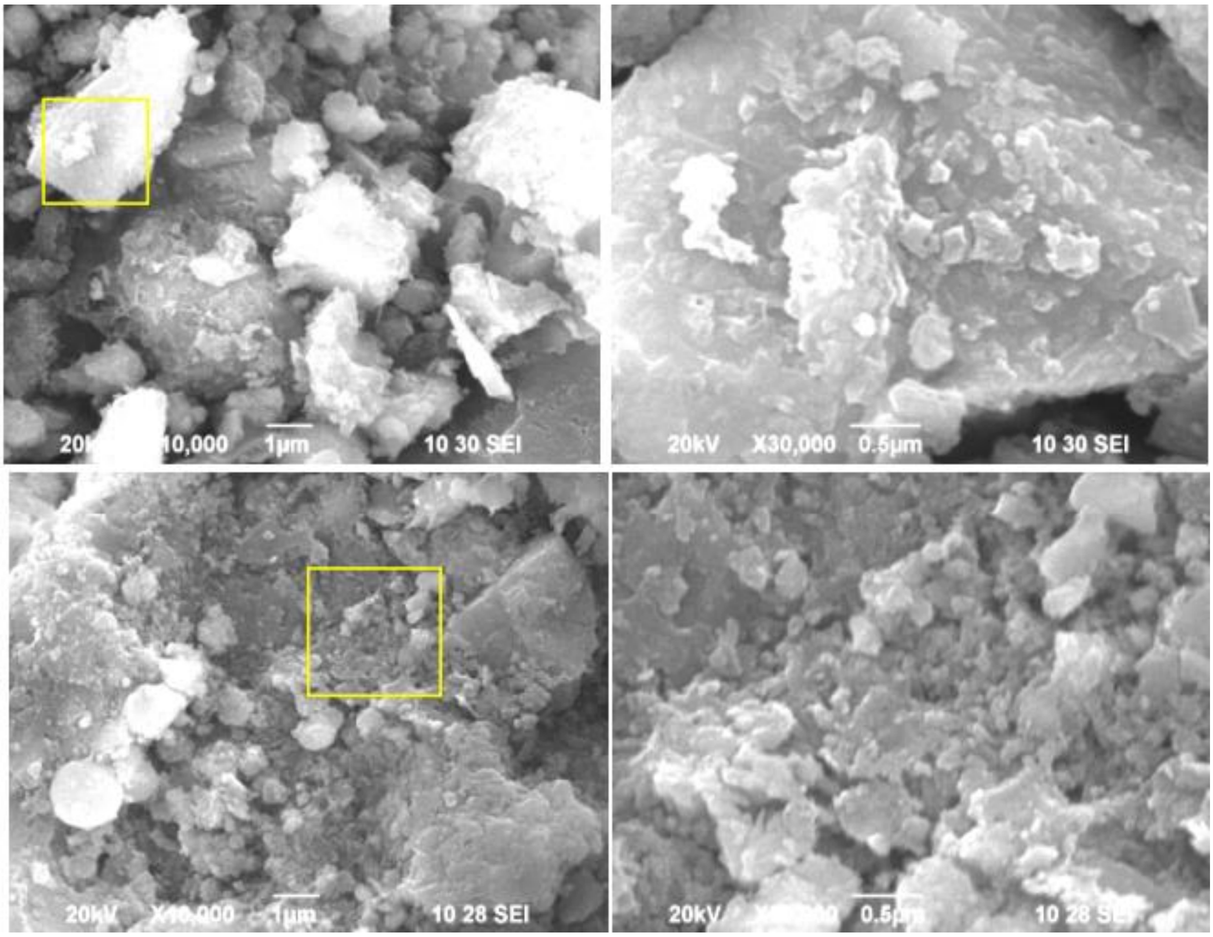
Exploratory Factor Analysis (EFA) serves as a systematic approach to uncovering the fundamental structure and relationships within a study's observed variables. It is a data reduction technique aimed at identifying latent factors or constructs that explain the variance in the data. The initial phase of EFA involves rigorous data preparation, including a thorough examination of collected responses for completeness and accuracy . Subsequently, the dataset undergoes scrubbing to address missing values adequately. Following data preparation, the suitability of the data for EFA is evaluated using measures such as the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity. These assessments provide valuable insights into sample size adequacy and the intercorrelation between variables, laying the groundwork for a robust exploratory factor analysis. Following the exploratory factor analysis (EFA), the final factor solution was interpreted to uncover latent constructs within the dataset. Variables that made significant contributions to each factor were identified, aiding in the characterization of these factors. The primary objective of employing the EFA methodology was to reveal latent constructs and elucidate the factor structure inherent in the dataset. This process facilitated the exploration of underlying dimensions and associations between variables, thereby offering valuable insights for subsequent analysis and interpretation. By identifying these latent constructs, researchers gain a deeper understanding of the complex relationships within the data, paving the way for further investigation and theoretical development.

6.2 SEM analysis

The study utilized SmartPLS 4 software to employ Partial Least Squares Structural Equation Modeling (PLS-SEM) for a comprehensive analysis of the relationships and effects among crucial factors affecting Building Information Modeling

(BIM) implementation in small construction projects, particularly focusing on green building and sustainability practices PLS-SEM was deemed appropriate for this investigation Handling Small Sample Sizes: PLS-SEM is well-suited for studies with limited sample sizes, making it an ideal choice for this research. Suitability for Exploratory Research: PLS-SEM is particularly suitable for exploratory research where constructs might not adhere to a normal distribution.

The study employed the PLS algorithm within SmartPLS 4 to examine the relationships between various factors related to BIM implementation and their impact on sustainability outcomes in small construction projects. These factors included energy efficiency analysis, resource optimization, collaboration, sustainable site planning, greenhouse gas emissions reduction, material selection, life cycle assessment, and prefabrication. To ensure the reliability and validity of the measurement model, the algorithm evaluated both convergent and discriminant validity. This was assessed by examining factor loadings, composite reliability, and average variance extracted (AVE) for each construct. High factor loadings, composite reliability values above a threshold (typically 0.7 or higher), and AVE values exceeding 0.5 indicate satisfactory convergent validity, ensuring that the measurement model accurately captures the latent variables.



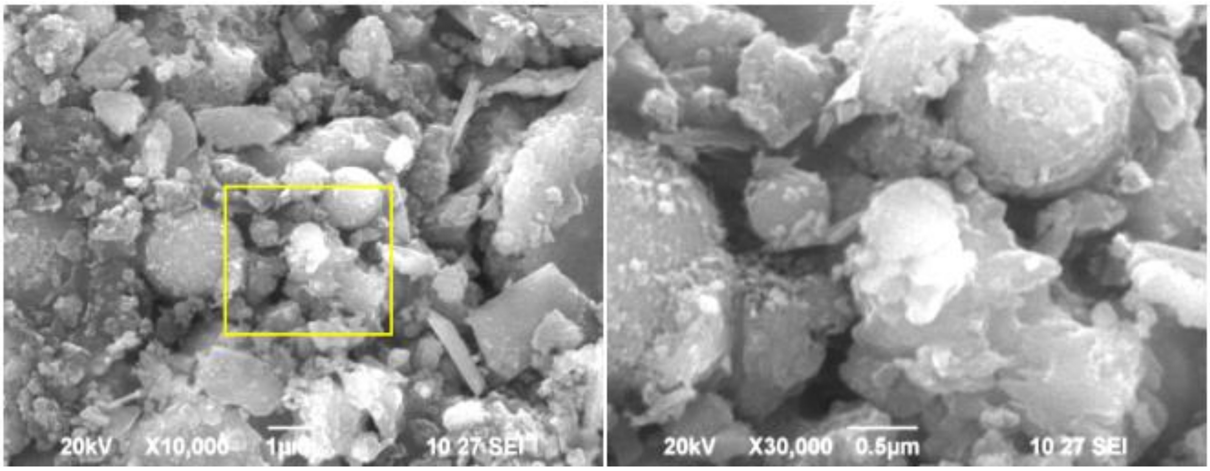


Figure 3 SEM Analysis

7.Conclusion

The integration of Building Information Modeling (BIM) with building rating tools has the potential to streamline and expedite the green certification process. However, it's apparent from the literature review that research in this area is limited, which may explain the prevalent manual approach to green building ratings. Among various building rating tools such as LEED, BREEAM, GBI, GreenRE, Green Mark, and BEAM Plus, LEED stands out as widely used for integration with BIM software, although the integration methods remain relatively underexplored. The existing research primarily focuses on leveraging BIM to enhance building sustainability by extracting information from BIM models, rather than automating the green certification process. Notably, while BIM's application in obtaining credits under energy efficiency subcategories is relatively mature, other subcategories such as water efficiency, location and transportation, material and resources, sustainable site, indoor environmental quality, innovation, and regional priority remain understudied within the context of BIM-building rating. To address these gaps, future research should delve into these underexplored subcategories to broaden the scope of BIM's utilization for green ratings. Additionally, it's worth noting that the reviewed publications predominantly concentrate on the integration of BIM and building rating tools, neglecting studies focused on utilizing BIM software to directly improve sustainability. This limitation underscores the need for expanded research efforts to explore the full potential of BIM in advancing sustainability practices within the built environment.

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