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BIM-DRIVEN OFFSITE CONSTRUCTION: PATHWAY TO EFFICIENCY, FUNCTIONALITY AND SUSTAINABILITY

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Abstract: In the fast-paced world of construction, Building Information Modeling (BIM) is revolutionizing offsite construction, leading to significant improvements in efficiency, functionality, and sustainability. This study examines BIM's critical role in enhancing offsite construction, aiming to showcase its potential to transform construction practices towards better efficiency and environmental care. By analyzing data from observations, discussions, and digital sources, the research investigates BIM's impact on offsite construction. The findings reveal BIM's key role in addressing traditional offsite construction challenges, with examples like Autodesk Revit enhancing 3D modeling, Open Studio reducing energy modeling errors, and ArchiCAD optimizing design processes. Also, Autodesk Insight speeds up project completion through energy analysis, and Flixo promotes collaboration with thermal bridge analysis. These tools, including WUFI for moisture and sustainability analysis, highlight BIM's ability to tackle ecological issues. Additionally, the integration of AI in ArchiCAD and SketchUp further advances rendering capabilities. The study concludes that BIM is essential for achieving top efficiency, functionality, and sustainability in offsite construction. It urges stakeholders to embrace BIM fully, leading to a shift towards more sustainable and efficient construction methods. Recommendations based on results include investing in BIM development and promoting its widespread adoption. Future research should assess BIM's quantitative and qualitative impact, explore its accessibility, and investigate its long-term sustainability effects.

Keywords: Building Information Modeling, Efficiency, Sustainability, Offsite construction, Artificial Intelligence

1 INTRODUCTION

Offsite construction, involving the prefabrication of building components in a controlled environment and their subsequent assembly on-site, is the future of construction due to its efficiency, quality control, and seamless integration with Building Information Modeling (BIM) technology that enhances design, coordination, and communication (Nguyen et al., 2024). BIM is a digital representation that supports decision-making throughout a building's lifecycle. BIM allows for a holistic, three-dimensional approach to managing construction projects by integrating design, planning, construction, and operational data. This leads to greater efficiency, productivity, and sustainability in the construction industry (Li, 2024).

BIM enhances design and construction processes by enabling stakeholders to visualize projects in detail, streamline workflows, and foster collaboration. It also reduces waste and errors, resulting in cost savings and improved project outcomes. BIM's ability to simulate aspects of a building's performance empowers designers and engineers to make informed decisions that enhance sustainability and resilience (Hei et al., 2024; Yin et al., 2019). Indeed, since the fabrication of computers in 1949, significant advancements have been made in the field of Building Information Modeling (BIM). Notably, the Soviet Block saw the emergence of two programming visionaries, Leonid Raiz and Gábor Bojár, who played important roles in shaping the BIM market. Gábor Bojár rebelled against the communist government and founded ArchiCAD in 1982 in Budapest, Hungary. In 1984, ArchiCAD made its debut as the first BIM software accessible on a personal computer (Archdaily, 2024).

BIM software plays a critical role in traditional construction challenges. Notable examples include Autodesk Revit enhancing 3D modeling capabilities (Stine, 2023), Open Studio reducing energy modeling errors (Spielhaupter & Mahdavi, 2023), and ArchiCAD optimizing design processes (Szalai et al., 2023). Integration of artificial intelligence in software like ArchiCAD and SketchUp further advances rendering capabilities. Tools such as SketchUp and Autodesk Insight have demonstrated their contribution to minimizing waste and expediting project completion through accurate material estimation and energy performance analysis. While tools like Flixo are used to promote collaboration through thermal bridge analysis and WUFI to provide comprehensive moisture and sustainability assessments in addressing ecological concerns effectively (Huang et al., 2021).

BIM has demonstrated significant potential to revolutionize off-site construction practices, enhancing efficiency, functionality, and sustainability. Empirical data from various case studies highlights these benefits. For instance, the McHenry Row redevelopment project in Baltimore utilized BIM to coordinate prefabricated wall panels with mechanical, plumbing, and electrical systems, resulting in efficient and accurate material delivery and keeping the project on schedule and within budget (Bdcnetwork, 2024). Another example is the Lynch Hill project in the United of Kingdom, where BIM facilitated clash detection and streamlined construction processes, reducing the need for additional site work, and ensuring timely project completion(Pdctoday, 2024). Additionally, a study on prefabricated bridge construction demonstrated that integrating BIM with Design for Manufacturing and Assembly (DfMA) principles significantly reduced assembly errors and improved overall project outcomes by enabling precise preassembly analysis and error detection (Nguyen et al., 2024).

However, offsite construction—a sector poised for growth—has not fully explored the integration of BIM for many years. Offsite construction, with its focus on efficiency and sustainability, can benefit greatly from BIM. By prefabricating components in a controlled factory environment and assembling them on-site, offsite construction can reduce construction time, minimize environmental impact, and ensure higher quality outcomes. BIM has the potential to further enhance these advantages (He et al., 2021; Likita et al., 2024). This research aims to investigate the impact of using BIM in off-site construction projects. It will focus on design performance analysis, including energy efficiency, structural analysis, material optimization, cost estimation and reduction, time savings, sustainability analysis, and design technology. The study aims to showcase BIM's potential to revolutionize off-site construction practices and improve efficiency, functionality, and sustainability by analyzing empirical data.

2 RESEARCH METHODOLOGY

This study employs a comprehensive review of method data to assess the impact of BIM on offsite construction. Data were collected through structural reviews of existing literature and case studies of projects utilizing BIM tools. The analysis involved both thematic analysis of qualitative data and quantitative data to explore the evolution of BIM technology. The first step was to identify the performance of BIM, its associated software, functionality, and impact on offsite construction. The next step was to investigate the potentiality of BIM technology in off-site construction. Lastly, the incorporation of AI into BIM technology was also evaluated. Figure 1 depicts the used procedure and the subsequent methodology.

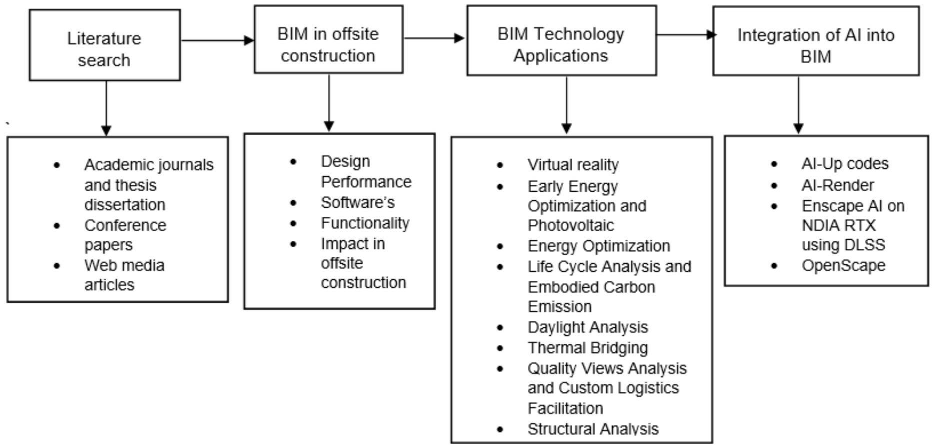


Figure 1: Flowchart used in the present study

3 BIM IN OFFSITE CONSTRUCTION: ROLE OF DESIGN PERFORMANCE ANALYSIS

BIM has become an integral part of offsite construction, offering a digital platform that enhances design performance across various critical aspects. By integrating BIM, offsite construction benefits from improved energy efficiency, structural integrity, material optimization, cost management, time savings, sustainability, and advanced design technology. In this study, BIM tools are defined as software applications that facilitate the digital representation and management of building information throughout the lifecycle of a construction project. This includes tools specifically designed for 3D modeling, energy analysis, structural analysis, and project management. Examples include Autodesk Revit, Open Studio, and ArchiCAD. Tools like Rhino and Miro are included due to their integration capabilities with BIM workflows, enhancing design and collaboration processes. This comprehensive approach to construction management leverages a suite of specialized software tools, each contributing uniquely to the project's success. Table 1 highlights the specific functionality, impact, and potentiality of BIM software in offsite construction.

Table 1: Design Performance Analysis in Offsite Construction

Design Performance Analysis	**BIM Software Examples**	**Functionality**	**Impact on Offsite Construction**	**Sources**
Energy Efficiency	Autodesk Insight, OpenStudio, ClimateStudio	Energy modeling for efficient design and scenario optimization.	Improved energy performance and compliance with sustainability standards.	(Bimenergy, 2024; Strusoft, 2024)
Structural Analysis	Autodesk Revit, Rhino	Detailed structural integrity and performance analysis.	Enhanced structural reliability and adherence to building codes.	(Idecad, 2024), (Autodesk, 2024)
Material Optimization	SketchUp, Tally	Detailed modeling for waste minimization and resource efficiency.	Reduced material waste and optimized resource utilization.	(Asl et al., 2015)
Cost Estimation and Reduction	Autodesk Revit, Tally	Insight into material, labor, and cost for informed budgeting.	More informed budgeting and potential cost savings.	(Asl et al., 2015)
Time Savings	Miro, Enscape	Rapid prototyping, visualization, and iterative design.	Shorter project timelines and increased efficiency.	(Simscale, 2024)

Sustainability Analysis	WUFI, Tally	Environmental impact assessment of materials and methods.	Ensured adherence to green building standards and reduced environmental impact.	(Asl et al., 2015)
Design Technology	Enscape, Rhino	Immersive visualization and design alternative exploration.	Fostered creativity and technical excellence in construction design.	(Simscale, 2024)

4 BUILDING INFORMATION MODELING TECHNLOGY APPLICATIONS

Fast-advancing BIM technology is improving offsite construction efficiency and precision. Indeed, virtual reality (VR) lets stakeholders see a project before construction, boosting comprehension and collaboration. Early Energy Optimization tools in BIM help designers make energy-efficient decisions early in the design process, creating more sustainable buildings. BIM facilitates Life Cycle Analysis, including Embodied Carbon Emission assessments, to show a building's environmental impact over its lifetime. Daylight Analysis in BIM optimizes natural light in architectural projects, improving occupant comfort and energy efficiency. Thermal Bridging Analysis technologies find energy leaks, improving building insulation and efficiency. Quality views created by BIM tools can identify project flaws before they occur on site. Wind Analysis lets structures endure local winds, ensuring safety and stability.

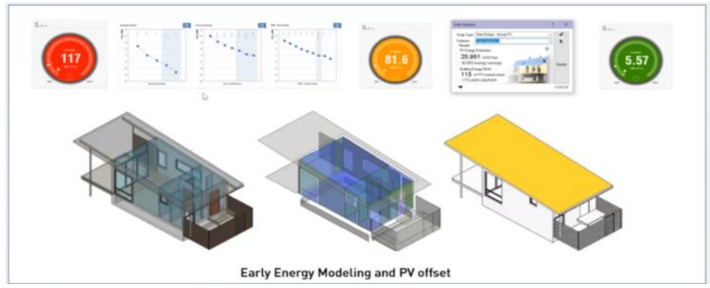
4.1 Virtual reality using Revit Autodesk

Virtual reality (VR) is a simulated experience that can be similar to or completely different from the real world, employing interactive 3D environments that users can explore and manipulate. VR typically requires users to don headsets or goggles that provide immersive visual and auditory stimuli, creating the illusion of being physically present in a virtual space. As shown in Figure 1(a), a VR headset is used by professionals to engage with a three-dimensional model created in Autodesk Revit, the leading BIM software. Indeed, the screen in front of the individual immerses them in a detailed virtual representation of an offsite construction project. This functionality allows for a comprehensive review of the design, enabling the user to walk through the virtual space, inspect different aspects of the model, and make informed decisions about the project's development. VR technology, when paired with Autodesk Revit, provides a powerful tool for visualizing complex structures, facilitating better design communication, and planning before the actual construction begins on site.

4.2 Early Energy Optimization and Photovoltaic (PV) using Autodesk Insight

Early Energy Modeling and PV offset using Autodesk Insight are powerful tools for architects and engineers in the offsite construction industry. Figure 2(b) illustrates the various stages of energy modeling, which is important for optimizing the energy efficiency of buildings starting from the earliest design phases. The graphical representations and detailed views of a building's energy model allow for the analysis and adjustment of different design elements in order to reduce energy consumption. In the context of offsite construction, this early energy optimization is particularly valuable. It allows for the optimization of prefabricated building components for energy efficiency prior to their on-site assembly. This proactive approach can result in significant improvements in the overall sustainability profile of the building, reducing both operational costs and environmental impact. Offsite construction projects can achieve a higher standard of energy performance, aligning with the growing demand for green building practices and compliance with sustainability standards, by utilizing Autodesk Insight for energy modeling.

(a)



(b)

Figure 2: (a) Virtual reality; (b) Early Energy Modeling (Bimchapters, 2024)

4.3 Energy Optimization using Revit Autodesk + Open Studio + Energy Plus

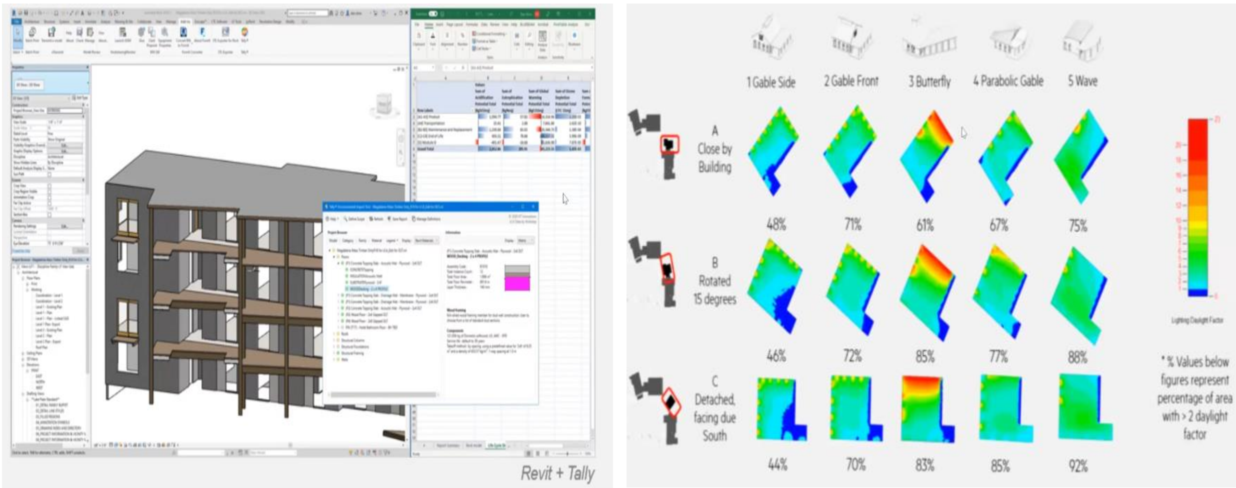
The combination of Revit Autodesk, Open Studio, and Energy Plus offers a strong framework for energy optimization in the context of offsite construction, as shown in Figure 3(a). These tools work together to create a comprehensive energy model that predicts and enhances building performance before construction. Revit Autodesk is the foundation for BIM, where initial design and 3D modeling occur. Open Studio, an extension of Revit, allows for detailed energy analysis and simulation. Energy Plus performs dynamic whole-building energy simulation, which is crucial for understanding thermal loads, systems, and environmental conditions. Using these tools in offsite construction projects enables designers and engineers to optimize energy use and sustainability from the start. Designers and engineers can adjust the construction of prefabricated components to maximize energy efficiency by pre-analyzing various energy scenarios and their impacts. This proactive approach ensures that once the components are assembled onsite, the building will operate at optimal energy performance levels, resulting in reduced operational costs and a smaller carbon footprint. This aligns with the increasing demand for sustainable building practices.

4.4 Life Cycle Analysis (LCA) and Embodied Carbon Emission

Embodied Carbon Emission refers to the total greenhouse gas emissions (measured in carbon dioxide (CO2) equivalents) resulting from the manufacturing, transportation, installation, maintenance, and disposal of building materials throughout the entire lifecycle of a building or infrastructure. Life Cycle Analysis (LCA) systems and Embodied Carbon Emission assessment are important components in offsite construction when utilizing tools like Revit Autodesk and Tally, as depicted in Figure 3(a). These software applications work together to evaluate the environmental impact of building materials and processes throughout a building's life cycle. In offsite construction, where components are prefabricated in a factory setting, LCA becomes particularly important for identifying and reducing carbon emissions before construction begins on site. Revit Autodesk provides the detailed 3D modeling necessary for accurate LCA, while Tally specializes in quantifying the embodied carbon of building materials, considering all stages from extraction to installation. This integration allows for a comprehensive assessment of a project's environmental footprint, enabling designers to make informed decisions that can lead to more sustainable construction practices. Offsite construction projects can significantly reduce their overall carbon impact, contributing to the industry's move towards greener building solutions, by applying LCA early in the design phase.

4.5 Daylight Analysis using Autodesk Insight

As shown in Figure 3(a) in the attachment, Autodesk Insight is utilized for conducting Daylight Analysis in a classroom setting, an essential aspect of offsite construction projects. This tool allows for the assessment of natural light within space, providing valuable data that can inform design decisions to optimize daylight exposure and enhance the energy efficiency of the building. Such analysis is crucial in offsite construction to maximize natural lighting, thereby reducing reliance on artificial lighting and lowering energy costs. Insight's daylight analysis can help, for example, create comfortable and sustainable educational environments by simulating and visualizing the distribution of light throughout the classroom or a house (using Rhino + Climate Studio, for example) in the offsite construction industry. This process not only contributes to the well-being of occupants but also aligns with green building standards, making it a key step in the design phase of offsite construction projects.



(a) (b)

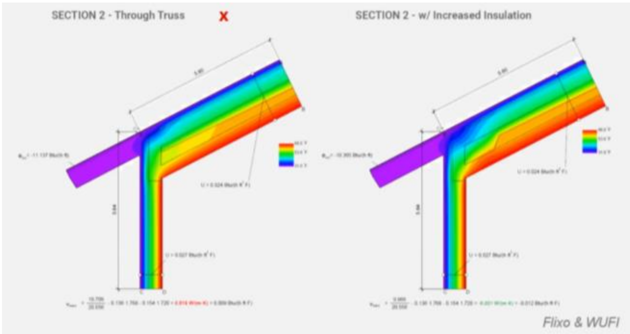
Figure 3: (a) Life Cycle Analysis, (b) Daylight Analysis (Bimchapters, 2024)

4.6 Thermal Bridging Analysis using Flixo and WUFI

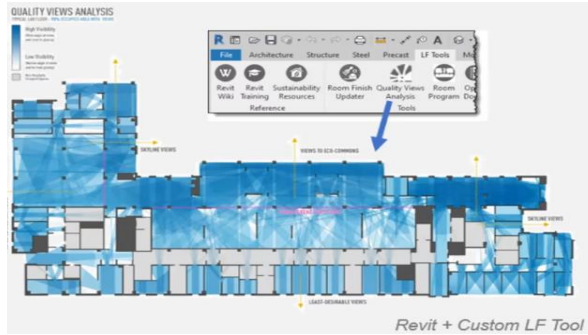
Thermal bridging occurs when heat passes through more conductive materials in a building's envelope, bypassing the insulation and resulting in energy loss. This can significantly impact the energy efficiency and comfort of a building. Thermal Bridging Analysis uses tools like Flixo for visualization and quantification of heat flow and WUFI for hygrothermal analysis, which are essential in offsite construction to address these issues during the design phase before component assembly on-site. Figure 4(a) illustrates a comparative analysis of thermal performance in a building section, with one scenario showing a through truss (a common thermal bridge point) and another with increased insulation to mitigate heat flow. Identifying and addressing thermal bridges early in the design phase is essential in offsite construction, where components undergo manufacturing in a controlled environment before assembly on-site. WUFI provides hygrothermal analysis to understand how heat and moisture interact within building materials, while Flixo visualizes and quantifies heat flow through these problematic areas. By using these tools, designers can improve the thermal efficiency of building envelopes, resulting in structures that are more energy-efficient and comfortable for occupants. This analysis is particularly important for offsite construction as it ensures that prefabricated elements contribute to the overall energy performance of the building, aligning with sustainability goals and reducing long-term operational costs.

4.7 Quality Views Analysis using Autodesk Revit and Custom Logistics Facilitation (LF)

Autodesk Revit, in conjunction with Custom Logistics Facilitation (LF) software, is designed to enhance the quality assurance process in offsite construction. The visualization of the quality view analysis is important for offsite construction projects, where precision and adherence to specifications are paramount. The Custom LF tool integrated with Revit provides additional functionality tailored to offsite construction needs. It enables the creation of quality views that can be used to assess the manufacturability of components, ensure that they meet quality standards, and identify potential issues before fabrication, as depicted in Figure 4(b). This tool streamlines the quality control process, making it more efficient and effective. By using Revit and the custom LF tool, stakeholders in offsite construction can maintain high standards of quality while optimizing the production and assembly of building components, ultimately leading to better project outcomes.



(a)



(b)

Figure 4:Thermal Bridging Analysis with Flixo and WUFI; (b) Quality View Analysis Using Revit + Custom LF Tool Interface (Bimchapters, 2024)

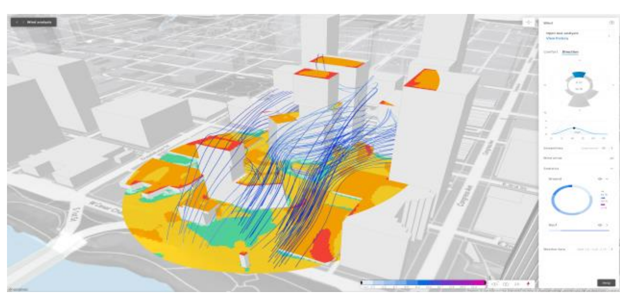
4.8 Structural Analysis using Tally

Structural Analysis can be done using Tally in offsite construction projects by comparing the Global Warming Potential (GWP) of concrete and steel, as shown in Figure 5(a). This analysis is important for determining the environmental impact of different structural materials because, where components are often prefabricated and assembled on-site, the choice of material can significantly influence the project's carbon footprint. Tally, integrated with Revit, allows for a detailed comparison of materials like concrete and steel, not only in terms of structural performance but also their environmental impact. Indeed, a higher GWP compared to steel suggests that choosing steel could reduce the project's overall emissions. This kind of analysis is essential for offsite construction as it informs decisions that can lead to more sustainable building practices. Designers and builders can opt for materials that not only meet structural requirements but also align with sustainability goals, ultimately contributing to the construction industry's efforts to mitigate climate change, by comparing the embodied carbon of concrete and steel.

4.9 Wind and Traffic Noise Analysis using Autodesk Forma + AI + Landscape Architecture

Figure 5 (b) depicts the application of Autodesk Forma, which utilizes AI for Landscape Architecture, in conducting wind analysis and traffic noise analysis for offsite construction projects. The software provides a detailed visualization of how wind patterns and traffic noise can affect a proposed construction site, which is essential for planning and designing buildings that are not only structurally sound but also comfortable for future occupants. In offsite construction, where components are manufactured in a controlled environment before being assembled on-site, understanding environmental factors such as wind and noise is crucial. It allows for the design and fabrication of building elements that can withstand local wind conditions and mitigate the impact of traffic noise. Once assembled, this preemptive analysis guarantees a safe and quiet environment for its users. Autodesk Forma's AI capabilities enhance this process by predicting outcomes based on vast amounts of data, leading to more accurate and efficient design solutions for offsite construction projects.

(a)



(b)

Figure 5: (a) Structural Analysis using Tally; (b) Autodesk Forma which used AI for Landscape Architecture (Bimchapters, 2024)

5 INTEGRATION OF ARTIFICIAL INTELLIGENCE (AI) INTO BIM

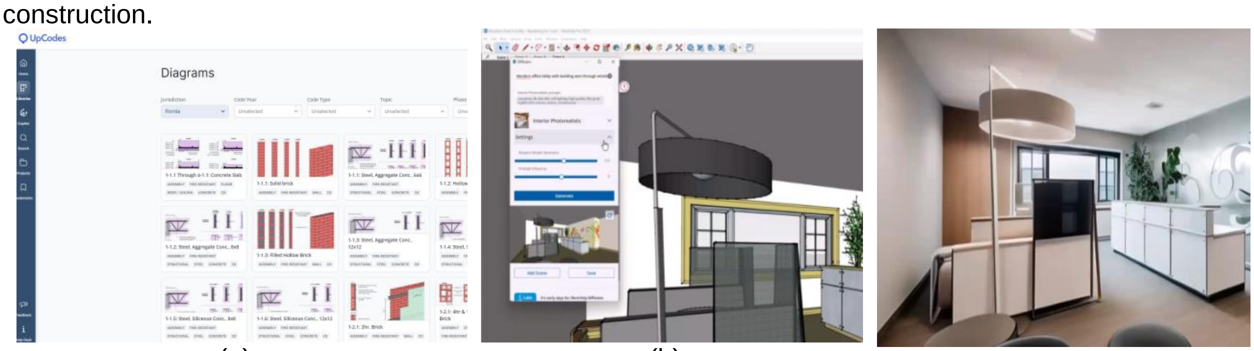
The integration of Artificial Intelligence (AI) into BIM is a significant advancement for the construction sector, particularly in offsite building. Advanced AI techniques in BIM enhance design, decision-making, and offsite project outcomes. BIM can now anticipate and address complex issues, automate repetitive tasks, and analyze large quantities of data rapidly and accurately through machine learning, knowledge-based systems, and other AI subfields. Currently, AI also enables design customization, facilitating freedom and innovation while adhering to building regulations and standards. AI also plays a role in the operation of buildings. It can monitor building performance, predict maintenance requirements, and optimize energy usage, thereby extending the building's lifespan. As offsite building continues to expand, AI in BIM will become increasingly important, providing companies that embrace these cutting-edge technologies with a competitive advantage.

5.1 AI-UpCodes (Building codes)

AI-UpCodes is a transformative application of AI in BIM, particularly relevant to offsite construction (Figure 6(a)). AI-UpCodes can automate the process of ensuring that building designs comply with the latest building codes and regulations. This AI-powered tool can analyze BIM models in real-time, identifying potential compliance issues and offering corrective recommendations. In offsite construction, where components are manufactured away from the final building site, adherence to building codes is crucial for the seamless assembly and certification of the structure. By Integrating AI-UpCodes into the BIM process, offsite construction projects can benefit from increased accuracy in code compliance, which is essential for obtaining building permits and avoiding costly post-construction modifications. This tool also enhances collaboration among architects, engineers, and code officials by providing a clear and consistent understanding of code requirements. Ultimately, AI-UpCodes streamlines the design review process, reduces the risk of human error, and ensures that offsite-constructed buildings meet the highest standards of safety and quality (Upcodes, 2024).

5.2 SketchUp and ArchiCAD Diffusion AI Render

Figure 6(b) depicts a 3D rendering interface, while Figure 6(c) illustrates a high-quality render of an interior space, likely generated using AI-enhanced tools within SketchUp (Sketchup, 2024). These advanced rendering capabilities allow for photorealistic visualizations of designs, which are crucial for client presentations, design validation, and decision-making processes. In offsite construction, the ability to visualize the final product with such clarity before manufacturing begins is invaluable. It enables the detection of design issues, enhances aesthetic appeal, and ensures that the prefabricated components will meet the project's visual and functional requirements. ArchiCAD also offers similar AI-powered rendering tools, which provide architects and designers with realistic visual feedback on their designs. Making informed decisions about materials, lighting, and other design elements before the offsite construction process starts requires this feedback. The use of AI in rendering not only saves time but also significantly improves the quality and accuracy of the final renders, facilitating a smoother transition from design to construction.

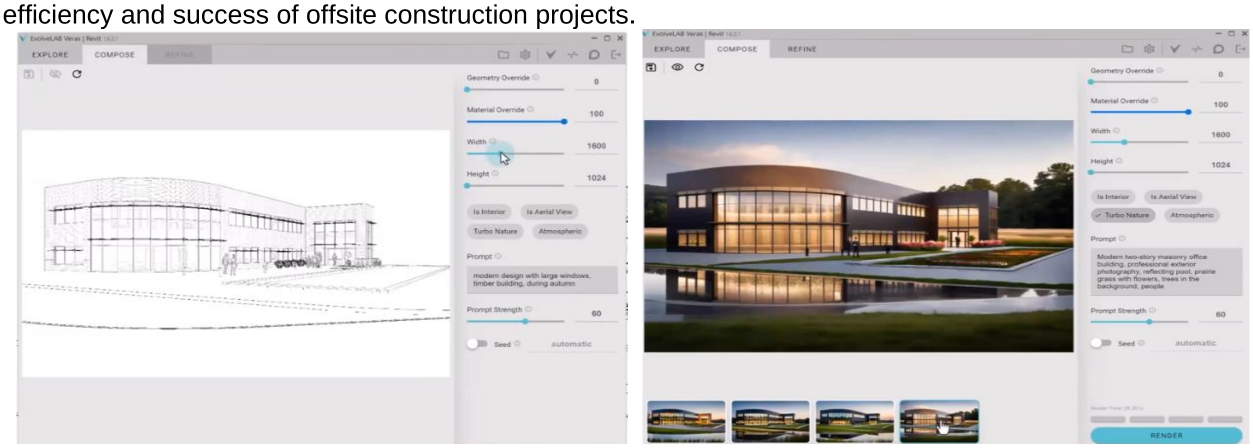


(a) (b) (c)

Figure 6: (a) UpCodes interface; (b) Sketchup 3D rending; (c) AI-Sketchup 3D rendering (Bimchapters, 2024)

5.3 Veras AI Render in Revit

Veras AI Render in Revit (see Figure 7(a)) represents a significant advancement in architectural visualization in the context of BIM and offsite construction. As shown in Figure 7(b), Veras AI Render harnesses the power of artificial intelligence to produce photorealistic images directly from Revit models. This AI-driven rendering tool streamlines the visualization process, allowing architects and designers to generate high-quality images with realistic lighting, textures, and materials, which are essential for client presentations and design reviews. For offsite construction projects, where precision and clarity in the pre-fabrication phase are crucial, Veras AI Render enhances the ability to foresee and address potential design issues before production begins. It provides a clear and accurate representation of the final product, facilitating better communication among stakeholders and ensuring that the prefabricated components align with the project's aesthetic and functional requirements. The integration of AI rendering into the BIM workflow elevates the design process, enabling more informed decision-making and contributing to the efficiency and success of offsite construction projects.

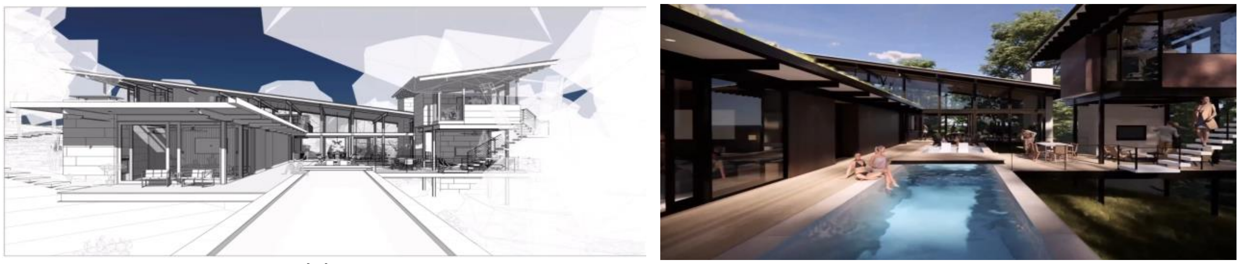


(a) (b)

Figure 7: Revit 3D animation (a); (b) 3D rendering with Veras AI (Bimchapters, 2024)

5.4 Rendering using Enscape AI on NVDIA RTX using DLSS

In the field of BIM and offsite construction, the combination of Enscape AI, NVIDIA RTX graphics cards, and Deep Learning Super Sampling (DLSS) technology is a significant advancement in architectural rendering. Figure 8(a) and (b) demonstrate the powerful combination's ability to bring highly detailed and realistic visualizations of building designs to life from 3D rendering to 4D animation. NVIDIA's DLSS uses artificial intelligence to enhance animation in real time, resulting in high-quality visuals with smoother frame rates and reduced computational strain. This is especially beneficial for complex architectural models. Additionally, NVIDIA RTX cards enable real-time ray tracing, allowing for the creation of photorealistic imagery that accurately portrays the behavior of light, reflections, shadows, and textures. This level of detail is crucial in offsite construction, where precision is of utmost importance. It enables the early identification of design issues, guaranteeing an accurate representation of the final product prior to the commencement of the prefabrication process. Such visual clarity assists stakeholders in making well-informed decisions, providing a comprehensive understanding of the project's result. The integration of these technologies into BIM workflows streamlines the design process by enabling rapid iterations and timely decision-making, as well as enhancing collaboration among architects, builders, and clients. All parties involved gain a shared and clear vision of the project, which is particularly valuable in the context of offsite construction, where components are manufactured remotely. Additionally, visually stunning renderings serve as a powerful marketing tool for offsite construction companies, showcasing their capabilities and attracting new clients. Overall, the utilization of Enscape AI on NVIDIA RTX with DLSS technology significantly enhances the quality, efficiency, and communication of the design and rendering processes in offsite construction projects.



(a) (b)

Figure 8: (a) Enscape 3D rendering (b); 4D simulation with AI on NVDIA RTX using DLSS (Bimchapters, 2024)

5.5 OpenScape using AI for Remodeling a Building

OpenSpace utilizes AI technology to revolutionize building remodeling in the context of BIM and offsite construction. OpenSpace setup allows for immersive 3D scanning and image capture of on-site conditions, which are then seamlessly integrated into the BIM model for precise remodeling efforts. This technology is particularly advantageous for offsite construction because it enables accurate documentation of existing conditions, which can inform the prefabrication process. OpenSpace's AI component processes the captured data to create detailed and navigable virtual representations of the site. This facilitates effective collaboration among project teams, even when they are working from remote locations. Consequently, any modifications or prefabricated elements are based on the most up-to-date site information, resulting in seamless integration during the construction phase and reducing the likelihood of costly errors or rework. OpenSpace's AI capabilities enhance the adaptability and efficiency of offsite construction practices, making it an invaluable tool for modern remodeling projects.

6 CONCLUSION

The integration of advanced BIM technologies and methodologies has led to improvements in the design, planning, and execution of construction projects. For instance, virtual reality has transformed stakeholder engagement through immersive pre-construction walkthroughs. Early energy optimization and life cycle analysis tools enable informed, sustainable design choices. Daylight and thermal bridging analysis contribute to energy-efficient and comfortable living spaces, while quality views identify potential design conflicts. The findings emphasize the need for stakeholders to embrace BIM and advocate for sustainable and efficient construction practices. BIM has proven to minimize waste and expedite project completion, demonstrating its importance in achieving top-tier outcomes. The integration of AI in tools like ArchiCAD and SketchUp provides stakeholders and clients with visual clarity on prospective projects and demonstrates the future impact of the evolution of AI in the BIM and offsite construction industries. Looking ahead, the study recommends continued investment in BIM development and widespread adoption across the offsite construction industry. Future research should assess the quantitative and qualitative impact of BIM, explore its accessibility to a broader range of professionals, and investigate its long-term sustainability effects with the ongoing advance of AI. Additionally, certain aspects remain underexplored, such as the quantitative assessment of productivity gains, supply chain integration, and interoperability challenges across different software platforms. Additionally, potential barriers to broader adoption, including high initial costs, lack of skilled workforce, and resistance to change in traditional construction practices, need to be addressed through targeted initiatives and industry-wide collaboration. The goal is to ensure that BIM-driven offsite construction becomes a pathway to efficiency and sustainability, serving as a blueprint for the future of construction practices globally. This study sets the foundation for a time when BIM-powered offsite construction became a model of innovation, effectiveness, and environmental responsibility.

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