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FULL LENGTH ARTICLE

Integrating BIM and Artificial Intelligence for Multi-Dimensional Sustainability in Post-Conflict Reconstruction

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ABSTRACT

Post-conflict reconstruction often prioritizes speed and cost over long-term sustainability, leading to environmental, social, and economic inefficiencies. This study proposes an integrated framework that combines Building Information Modeling (BIM) and Artificial Intelligence (AI) to enhance multi- dimensional sustainability in reconstruction projects. An exploratory explanatory case study methodology was adopted, analyzing two Syrian case studies—a service building in Tartous and the Al-Qarabis neighborhood in Homs—through BIM-based simulations and AI-driven optimization. BIM served as the core data platform, while AI facilitated scenario analysis and optimization across both design and operational stages. Sustainability indicators were explicitly mapped to relevant Sustainable Development Goals (SDGs 7, 9, 11, 12, and 13). Results indicate that BIM–AI integration significantly improves energy efficiency, operational performance, spatial adequacy, and life-cycle cost effectiveness, effectively translating sustainability from a conceptual goal into measurable outcomes. The framework provides empirical evidence for operationalizing Building Back Better principles and offers a transferable methodology applicable to other post-conflict reconstruction contexts. Future studies could explore the incorporation of additional AI-driven decision support tools or expand the framework to diverse post- conflict regions to further validate its applicability and impact.

Keywords: Building Information Modeling (BIM) ▪ Artificial Intelligence (AI) ▪ Post-Conflict Reconstruction ▪ Multi-Dimensional Sustainability ▪ Sustainable Development Goals (SDGs) ▪ Decision-Support Systems ▪ Syria

1. INTRODUCTION

Post-conflict reconstruction represents one of the most complex and critical challenges facing contemporary urbandevelopment. Beyond the physical damage to buildings and infrastructure, post-conflict environments are characterized by severe resource scarcity, institutional fragility, social vulnerability, and urgent housing and service demands.[1] In such contexts, reconstruction processes often prioritize speed and cost reduction, frequently at the expense of long-term environmental performance, social well-being, and economic resilience. As a result, many post-conflict cities risk reproducing unsustainable urban patterns that exacerbate energy inefficiency, environmental degradation, and social inequity.[2] In recent years, sustainability has increasingly been recognized as a fundamental principle for post-conflict reconstruction, shifting the discourse from short-term recovery toward long-term development. International frameworks, including the concept of Building Back Better (BBB) and the United Nations Sustainable Development Goals (SDGs), emphasize the need for reconstruction strategies that are environmentally responsible, socially inclusive, and economically viable.[3] However, despite this growing theoretical consensus, translating sustainability principles into operational and measurable practices within post-conflict reconstruction projects remains a significant challenge, particularly in contexts with limited technical capacity and fragmented decision-making processes.[4] Digital technologies have been widely promoted as potential enablers of sustainable construction. Among these, Building Information Modeling (BIM) has emerged as a powerful platform for integrating geometric, environmental, and operational data throughout the building life cycle. BIM has demonstrated substantial potential in improving design coordination, reducing material waste, and supporting performance-based decision-making. Nevertheless, BIM applications in reconstruction projects—especially in post-conflict settings—often remain limited to visualization and documentation, without fully exploiting their capacity to support sustainability-oriented optimization and predictive analysis.[5] Artificial Intelligence (AI), on the other hand, has shown increasing effectiveness in addressing complex optimization problems related to energy consumption, operational efficiency, and life-cycle performance in the built environment. AI-based models enable the analysis of large datasets, identification of non-linear relationships, and generation of optimized scenarios that exceed the capabilities of conventional simulation tools. Despite these advantages, existing studies frequently treat AI as an isolated analytical layer, detached from integrated building information environments and rarely embedded within real-world reconstruction workflows.[6] A critical gap therefore exists at the intersection of post-conflict reconstruction, BIM-based digital workflows, AI-driven optimization, and sustainability frameworks. Current literature lacks integrated approaches that explicitly align BIM and AI applications with the multi-dimensional objectives of the SDGs, particularly within post-conflict contexts where sustainability trade-offs are most acute. Moreover, empirical evidence demonstrating how such integration can enhance environmental, social, and economic performance in real reconstruction projects remains limited.[7] In response to this gap, this study aims to develop and validate an integrated BIM–AI conceptual framework aligned with the Sustainable Development Goals to enhance multi-dimensional sustainability in post-conflict reconstruction projects. Using Syria as an empirical case study, the research investigates how the integration of BIM and AI can support data-driven decision-making, optimize building performance, and contribute to more resilient and sustainable reconstruction outcomes. By bridging digital construction technologies with global sustainability agendas, this study seeks to advance both theoretical understanding and practical implementation of sustainable reconstruction in post-conflict environments.

2. LITERATURE REVIEW

2.1 Post-Conflict Reconstruction and Sustainability

Post-conflict reconstruction has increasingly been conceptualized as a complex and long-term development process rather than a short-term technical response to physical destruction. [8] Early reconstruction approaches were primarily driven by urgency, focusing on rapid housing provision and infrastructure restoration, often resulting in fragmented urban growth, inefficient resource use, and long-term socio-environmental vulnerabilities. Recent literature, however, emphasizes that reconstruction decisions made immediately after conflict have lasting implications for urban resilience, social equity, and environmental performance. The concept of Building Back Better (BBB) has emerged as a central paradigm within post-conflict and post-disaster reconstruction discourse, advocating for reconstruction strategies that enhance resilience, inclusivity, and sustainability. Scholars argue that BBB extends beyond physical rebuilding to encompass governance structures, social recovery, and environmental stewardship. Despite its widespread adoption in policy frameworks and international development agendas, BBB has been criticized for its conceptual ambiguity and limited operationalization, particularly in conflict-affected contexts where instituti onal capacity and technical resources are constrained.[9] Sustainability in post-conflict reconstruction is further complicated by competing priorities, including urgent housing needs, limited financial resources, damaged infrastructure, and weak regulatory frameworks. Several studies highlight that sustainability objectives are often deprioritized in favor of speed and cost minimization, leading to reconstruction outcomes that replicate pre-conflict inefficiencies or introduce new environmental and social challenges. This tension underscores the need for tools and methodologies capable of supporting informed trade-offs between short-term recovery and long-term sustainability. Recent research increasingly recognizes that post-conflict reconstruction provides a critical opportunity to reorient urbandevelopment trajectories toward more sustainable and resilient models. [4] However, while the theoretical alignment between post-conflict reconstruction and sustainability is well established, the literature reveals a persistent gap between conceptual frameworks and practical implementation mechanisms. In particular, there is limited empirical research demonstrating how sustainability principles can be systematically embedded into reconstruction decision-making pr ocesses under post-conflict constraints.

2.2 BIM as a Decision-Support System for Sustainable Reconstruction

Building Information Modeling (BIM) has been widely acknowledged as a transformative technology within the construction industry, enabling integrated management of building information across design, construction, and operation stages. Beyond its initial role as a 3D visualization tool, BIM has evolved into a data-rich platform capable of supporting performance-based design, interdisciplinary coordination, and life-cycle analysis.[10] Numerous studies demonstrate BIM's potential to reduce material waste, improve energy performance, and enhance project efficiency in conventional construction contexts. [11] In the context of sustainable construction, BIM has been increasingly applied to support energy simulation, environmental assessment, and life-cycle cost analysis. By enabling the early evaluation of design alternatives, BIM facilitates more informed decision-making and improves the integration of sustainability considerations into the design process. However, the literature indicates that BIM-based sustainability assessments often remain limited to predefined scenarios and static simulations, constraining their ability to address complex, multi-objective optimization problems.[12] Within post-conflict reconstruction settings, BIM adoption remains uneven and underexplored. Existing studies suggest that BIM is frequently employed for documentation, quantity take-offs, and coordination purposes, rather than as a comprehensive decision-support system. Factors such as limited technical expertise, fragmented data availability, and institutional instability further restrict the effective use of BIM in these contexts. As a result, the potential of BIM to support sustainability-driven reconstruction strategies is rarely fully realized.[13] Moreover, current BIM-focused research tends to emphasize technical efficiency while underrepresenting broader social and economic dimensions of sustainability, particularly in fragile and conflict-affected environments. The absence of integrated analytical capabilities limits BIM's capacity to evaluate trade-offs between environmental performance, social well-being, and economic feasibility—a critical requirement for sustainable post-conflict reconstruction.[14] Recent scholarly discussions therefore call for extending BIM beyond its conventional applications toward more intelligent, adaptive, and context-aware decision-support systems. Such extensions require the integration of advanced analytical techniques capable of processing complex datasets, predicting performance outcomes, and optimizing design and operational decisions. This recognition provides a direct rationale for integrating BIM with Artificial Intelligence, particularly within post-conflict reconstruction contexts where uncertainty and resource constraints demand more robust and adaptive decision-making frameworks.

2.3 Artificial Intelligence for Sustainability Optimization

Artificial Intelligence (AI) has increasingly emerged as a critical enabler for sustainability optimization in the built environment, particularly in contexts characterized by complexity, uncertainty, and competing performance objectives. Unlike conventional simulation-based approaches, which rely on predefined scenarios and linear assumptions, AI-driven methods are capable of processing large datasets, identifying non-linear relationships, and generating optimized solutions across multiple performance criteria simultaneously.[15] These capabilities are particularly relevant for post-conflict reconstruction projects, where resource scarcity, fragmented data, and urgent decision-making requirements limit the effectiveness of traditional analytical tools. Within sustainability-oriented construction research, AI has been primarily applied to optimize environmental performance, especially energy consumption and system efficiency. [16] Machine learning algorithms and optimization techniques have demonstrated strong potential in predicting building energy behavior, identifying dominant performance drivers, and proposing optimized operational strategies. However, existing studies frequently treat AI as a standalone analytical layer, operating independently from integrated building information environments. This separation constrains the practical applicability of AI-driven optimization, particularly in reconstruction contexts where decision-making must be closely linked to spatial, material, and operational data. Integrating AI within a BIM-based digital environment addresses this limitation by embedding optimization processes directly within project information workflows. BIM provides structured, geometry-linked, and context-aware data, while AI enhances this environment with predictive and adaptive intelligence. When combined, BIM and AI enable iterative feedback loops in which design and operational parameters are continuously evaluated and optimized against sustainability objectives. This integration transforms sustainability optimization from a static evaluation exercise into a dynamic, data-driven decision-support process. From a multi-dimensional sustainability perspective, AI contributes not only to environmental optimization but also to economic and social performance enhancement. By incorporating life-cycle cost parameters and operational constraints into AI-driven analyses, [17] optimization outcomes extend beyond short-term energy reduction toward long-term economic viability. Moreover, AI-assisted evaluation of indoor environmental quality and spatial performance supports social sustainability objectives by improving occupant comfort and usability—dimensions that are often underrepresented in technical optimization studies. In post-conflict reconstruction contexts, the role of AI becomes even more critical due to heightened uncertainty and limited institutional capacity. AI-driven optimization supports informed trade-off analysis between speed, cost, and sustainability, enabling reconstruction stakeholders to prioritize interventions that maximize long-term value under constrained conditions. When explicitly aligned with sustainability indicators and mapped to the Sustainable Development Goals, AI-based optimization moves beyond technical efficiency to support broader development and resilience objectives. Overall, the integration of Artificial Intelligence within BIM-enabled workflows provides a robust foundation for sustainability optimization in post-conflict reconstruction. By bridging predictive analytics, performance optimization, and structured building information, AI functions as a strategic enabler of data-driven, SDG-oriented reconstruction practices rather than a purely computational tool.[18,19]

3. BIBLIOMETRIC ANALYSIS

This section presents a comprehensive bibliometric and qualitative analysis of previous studies addressing the integration of Building Information Modeling (BIM), Artificial Intelligence (AI), and sustainability, with particular attention to post-conflict reconstruction contexts. The analysis aims to identify research trends, influential contributors, and knowledge gaps, and to position the current study within the existing body of literature.

3.1 Inclusion and Exclusion Criteria

To ensure methodological rigor and relevance, a structured set of inclusion and exclusion criteria was applied during the literature selection process. The bibliometric dataset was constructed using peer-reviewed journal articles, conference papers, and high-impact review studies indexed in major scientific databases, including Scopus and Web of Science. To ensure methodological rigor and relevance, a structured set of inclusion and exclusion criteria was applied during the literature selection process. The bibliometric dataset was constructed using peer-reviewed journal articles, conference papers, and high-impact review studies indexed in major scientific databases, including Scopus and Web of Science. Inclusion criteria comprised: (i) publications explicitly addressing BIM, AI, sustainability, or their integration; (ii) studies focusing on construction, urban planning, or post-conflict reconstruction; (iii) articles published in English between 2010 and 2025 to capture the evolution of digital transformation in the construction sector; and (iv) studies published in indexed journals or internationally recognized conference proceedings. Exclusion criteria included: (i) non-peer-reviewed reports, editorials, and opinion papers; (ii) studies unrelated to the built environment or sustainability dimensions; (iii) publications lacking methodological transparency; and (iv) duplicated records across databases. After screening titles, abstracts, and full texts, only studies meeting all inclusion criteria were retained for analysis.

3.2 Bibliometric Analysis of Previous Studies

3.2.1 Publications per Year

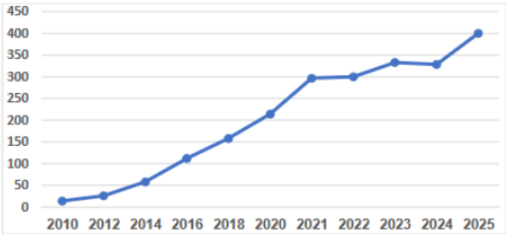

Figure 1. Number of studies published between 2013 and 2025

The annual distribution of publications demonstrates a clear and sustained growth in research related to BIM, AI, and sustainability. Prior to 2015, the number of publications was relatively limited, reflecting the early adoption stage of BIM and the nascent application of AI in the construction sector. From 2016 onward, a gradual increase can be observed, followed by a sharp acceleration after 2020. This surge coincide s with the rapid development of machine learning techniques, increased availability of digital construction data, and growing global emphasis on sustainable and resilient built environments.

3.2.2 Most Cited Authors

Table 1: Most cited authors in BIM–AI–sustainability research.

Author	Total Citations (approx.)	Main Research Focus
Cheng, J.C.P.	>2,000	BIM integration, AI applications in construction
Li, H.	>1,800	Digital construction, smart project management
Wang, J.	>1,500	Machine learning and data-driven BIM
Succar, B.	>1,200	BIM frameworks and maturity models
Volk, R.	>1,000	BIM for lifecycle and sustainability assessment

Citation analysis reveals a group of highly influential authors whose work has significantly shaped research directions in BIM-based digital transformation and AI-driven sustainability assessment. These authors typically operate at the intersection of construction management, computer science, and environmental sustainability. These authors are frequently cited due to their foundational contributions, including conceptual frameworks, implementation strategies, and large-scale review studies that continue to inform contemporary research.

3.2.3 Most Cited Articles

Table 2: Most cited articles related to BIM, AI, and sustainability.

Rank	Article	Year	Journal	Citations
1	Volk et al., "Building Information Modeling for existing buildings"	2014	Automation in Construction	>1,100
2	Succar, "Building information modelling framework"	2009	Automation in Construction	>750
3	Silva et al., "BIM, IoT and AI for smart and sustainable cities"	2018	Sustainable Cities and Society	>700
4	Azhar, "BIM: Trends, benefits, risks, and challenges"	2011	Leadership and Management in Engineering	>600

The most cited articles in this research domain are primarily comprehensive reviews and seminal framework papers that establish the theoretical and methodological foundations for BIM and AI integration. Their high citation counts reflect their broad applicability and long-term influence. 1 Volk et al., "Building Information Modeling for existing buildings" 2014 Automation in Construction >1,100 2 Succar, "Building information modelling framework" 2009 Automation in Construction >750 3 Silva et al., "BIM, IoT and AI for smart and sustainable cities" 2018 Sustainable Cities and Society >700 4 Azhar, "BIM: Trends, benefits, risks, and challenges" 2011 Leadership and Management in Engineering >600 0 2010 2012 2014 2016 2018 2020 2021 2022 2023 2024 2025 These studies are consistently referenced across subsequent research due to their methodological rigor and their role in bridging digital technologies with sustainability objectives.

3.2.4 Most Cited Journals

Table 3: Most influential journals publishing BIM–AI–sustainability research.

Journal	Scope	Impact and Relevance
Automation in Construction	Construction automation and BIM	Core journal for BIM research
Journal of Cleaner Production	Sustainability and environmental performance	High-impact sustainability outlet
Sustainable Cities and Society	Urban sustainability and smart cities	Strong focus on digital sustainability
Buildings	Building performance and digital tools	Rapidly growing BIM-focused journal
Sustainability	Multidisciplinary sustainability research	High publication volume and visibility

The analysis of source journals indicates that research on BIM, AI, and sustainability is concentrated in a relatively small number of high-impact journals specializing in construction technology, environmental performance, and sustainable development. Automation in Construction Construction automation and BIM Core journal for BIM research Production Sustainability and env ironmental performance High-impact sustainability outlet Sustainable Cities and Society Urban sustainability and smart cities Strong focus on digital sustainability Buildings Building performance and digital tools Rapidly growing BIM-focused journal Sustainability Multidisciplinary sustainability research High publication volume and visibility These journals provide the primary platforms for disseminating interdisciplinary research linking digital construction technologies with sustainability goals.

3.2.5 Most Cited Universities

Table 4: Leading universities in BIM–AI–sustainability research.

University	Country	Research Strength
Hong Kong Polytechnic University	China	BIM and smart construction
Tongji University	China	Sustainable urban development
Politecnico di Milano	Italy	Digital construction and sustainability
Curtin University	Australia	BIM implementation and management
Georgia Institute of Technology	USA	AI and data-driven construction

Institutional analysis highlights the dominance of universities withestablished research groups in construction informatics, sustainability science, and digital engineering. These institutions contribute significantly to both theoretical advancements and applied research. Tongji University China Sustainable urbandevelopment Politecnico di Milano Italy Digital construction and sustainability Curtin University Australia BIM implementation and management Georgia Institute of Technology USA AI and data-driven construction The growing presence of universities from developing and post-conflict regions in recent years indicates an expanding geographical scope of BIM and sustainability research.

3.2.6 Most Cited Countries

At the national level, research productivity and citation impact are strongly correlated wit h governmental support for digital construction and sustainability policies. Countries withearly BIM mandates and strong AI research ecosystems dominate the field. 1 China Highest publication volume and rapid growth 2 United States Strong AI and construction innovation 3 United Kingdom Early BIM adoption and policy leadership 4 Italy Active research in sustainable construction 5 Australia Focus on BIM standards and implementation Despite the dominance of these countries, emerging contributions from the Middle East and other post-conflict regions highlight increasing interest in leveraging BIM and AI as tools for sustainable reconstruction and resilience-building.

Table 5: Most influential countries in BIM–AI–sustainability research.

Rank	Country	Research Contribution
1	China	Highest publication volume and rapid growth
2	United States	Strong AI and construction innovation
3	United Kingdom	Early BIM adoption and policy leadership
4	Italy	Active research in sustainable construction
5	Australia	Focus on BIM standards and implementation

3.3 Qualitative Analysis of Previous Studies

To systematically examine the limitations and trends in existing research, a qualitative comparative analysis of key previous studies was conducted. This analysis focuses on identifying the types of studies, the relationships between independent and dependent variables, research objectives, principal findings, and proposed recommendations. The purpose of this analysis is to highlight recurring patterns, methodological gaps, and conceptual limitations in prior research related to BIM, Artificial Intelligence, sustainability, and post-conflict reconstruction. Table 6 summarizes the qualitative analysis and provides the foundation for identifying the research gap addressed in this study. Study Type Independent Variable Dependent Variable Research Objectives Key Findings Recommendations Ahmed et al. (2018) Empirical / Industry-based BIM adoption level Organizational performance Evaluate BIM performance improvement in AEC companies BIM improves coordination and efficiency but faces human and technical barriers Capacity building and institutional support for BIM adoption Chong et al. (2017) Analytical BIM-based energy modeling Energy performance Assess BIM effectiveness in energy-efficient design BIM supports early-stage energy analysis but lacks optimization capability Integration with advanced analytical tools Abanda et al. (2019) Review BIM-enabled sustainability tools Environmental performance Examine BIM applications for sustainable construction BIM enhances sustainability assessment but remains fragmented Development of integrated BIM-based sustainability frameworks Zhang et al. (2020) Experimental AI-based optimization algorithms Energy consumption Optimize building energy performance using AI AI significantly reduces energy use through predictive modeling Integration of AI with real building data environments Al-Saggaf & Jrade (2021) Empirical BIM maturity level Project sustainability outcomes Investigate BIM impact on sustainable project delivery Higher BIM maturity correlates with improved sustainability outcomes BIM maturity frameworks tailored to regional contexts Olanrewaju et al. (2022) Conceptual Digital construction strategies Post-disaster recovery efficiency Explore digital tools in recovery projects Digital tools impro -ve coordination but lack sustainability focus Align digital reconstruction with sustainability goals UN-Habitat (2020) Policy-oriented Reconstruction strategies Urban resilience Promote sustainable post-conflict urban recovery Sustainability is critical but weakly operationalized Need for data-driven decision-support systems Shi et al. (2021) Review AI applications in construction Decision-making quality Review AI-driven decision-support systems AI improves prediction and optimization but lacks BIM integration Embedding AI within BIM workflows Faraj et al. (2023) Applied case study BIM-based sustainable reconstruction Environmental & economic performance Assess BIM in post-conflict Syrian reconstruction BIM improves performance but lacks intelligent optimization Integration of BIM with AI for post-conflict contexts.

3.4 Similarities and Differences among Previous Studies

A comparative examination of previous studies reveals several important similarities and differences in how digital technologies, sustainability, and reconstruction contexts have been addressed within the existing literature. Similarities among Previous Studies Across the reviewed studies, there is a broad consensus on the growing importance of digital technologies—particularly Building Information Modeling (BIM) and Artificial Intelligence (AI)—in improving construction performance and decision-making processes. Most studies acknowledge BIM as an effective platform for enhancing coordination, visualization, and data integration throughout the building life cycle. Similarly, AI-based approaches are consistently recognized for their capacity to optimize complex performance variables, especially in relation to energy efficiency and operational performance. Another notable similarity lies in the widespread recognition of sustainability as a critical objective in contemporary constru ction and reconstruction practices. Many studies emphasize environmental performance, particularly energy reduction and resource efficiency, as central sustainability priorities. In addition, several researchers highlight the need for integrating sustainability considerations at early design stages to improve long-term outcomes, reinforcing the relevance of performance-driven decision-support tools. Furthermore, a common limitation identified across multiple studies is the fragmented treatment of digital technologies. BIM and AI are often investigated independently or sequentially, rather than as integrated components of a unified decision-support system. This fragmentation limits the capacity of existing approaches to address multi-dimensional sustainability challenges in a holistic manner. Differences among Previous Studies Despite these shared perspectives, significant differences exist in terms of research scope, methodological approaches, and contextual focus. One key distinction concerns the contextual setting of the studies. The majority of BIM-and AI-focused research has been conducted in stable economic and institutional environments, with limited attention to post-conflict or resource-constrained contexts. In contrast, studies addressing post-conflict reconstruction tend to prioritize governance, policy, and social recovery, often without incorporating advanced digital tools or quantitative performance analysis. Differences arealso evident in the treatment of sustainability dimensions . While environ mental sustainability—particularly energy performance—receives substantial atten-

Table 6. Qualitative Analysis of Previous Studies

Study	Type	Independent Variable	Dependent Variable	Research Objectives	Key Findings	Recommendations
Ahmed et al. (2018)	Empirical / Industry-based	BIM adoption level	Organizational performance	Evaluate BIM performance improvement in AEC companies	BIM improves coordination and efficiency but faces human and technical barriers	Capacity building and institutional support for BIM adoption
Chong et al. (2017)	Analytical	BIM-based energy modeling	Energy performance	Assess BIM effectiveness in energy-efficient design	BIM supports early-stage energy analysis but lacks optimization capability	Integration with advanced analytical tools
Abanda et al. (2019)	Review	BIM-enabled sustainability tools	Environmental performance	Examine BIM applications for sustainable construction	BIM enhances sustainability assessment but remains fragmented	Development of integrated BIM-based sustainability frameworks
Zhang et al. (2020)	Experimental	AI-based optimization algorithms	Energy consumption	Optimize building energy performance using AI	AI significantly reduces energy use through predictive modeling	Integration of AI with real building data environments
Al-Saggaf & Jrade (2021)	Empirical	BIM maturity level	Project sustainability outcomes	Investigate BIM impact on sustainable project delivery	Higher BIM maturity correlates with improved sustainability outcomes	BIM maturity frameworks tailored to regional contexts
Olanrewaju et al. (2022)	Conceptual	Digital construction strategies	Post-disaster recovery efficiency	Explore digital tools in recovery projects	Digital tools improve coordination but lack sustainability focus	Align digital reconstruction with sustainability goals
UN-Habitat (2020)	Policy-oriented	Reconstruction strategies	Urban resilience	Promote sustainable post-conflict urban recovery	Sustainability is critical but weakly operationalized	Need for data-driven decision-support systems
Shi et al. (2021)	Review	AI applications in construction	Decision-making quality	Review AI-driven decision-support systems	AI improves prediction and optimization but lacks BIM integration	Embedding AI within BIM workflows
Faraj et al. (2023)	Applied case study	BIM-based sustainable reconstruction	Environmental & economic performance	Assess BIM in post-conflict Syrian reconstruction	BIM improves performance but lacks intelligent optimization	Integration of BIM with AI for post-conflict contexts

tion in technical studies, social and economic dimensions are frequently underrepresented or addressed qualitatively. Only a limited number of studies attempt to evaluate susta inability as a multi-dimensional construct, and even fewer provide measurable indicators across environmental, social, and economic domains. Methodologically, prior research varies considerably in the degree of empirical validation. Several studies rely on conceptual frameworks, simulations, or hypothetical scenarios, whereas empirical case studies grounded in real reconstruction projects remain scarce. Where case studies do exist, they often lack integration with global sustainability frameworks such as the Sustainable Development Goals (SDGs), reducing their applicability for policy-oriented decision-making. Finally, a critical difference emerges in how sustainability outcomes arealigned with broader development agendas. While policy-oriented reports freq uently reference SDGs and resilience frameworks, technical studies on BIM and AI rarely establish explicit or measurable links to these global objectives. This disconnect limits the strategic relevance of digital construction research in informing sustaina ble post-conflict reconstruction policies.

4. RESEARCH GAP AND CONTRIBUTION

Despite growing research on sustainable construction, digitalization, and post-conflict reconstruction, the literature remains fragmented. Studies on post-conflict reconstruction primarily address policy, governance, and social recovery, often treating sustainability conceptually without operational tools. Conversely, BIM and AI research focuses on performance optimization and construction management in stable contexts, with limited consideration of post-conflict realities. Integration of BIM, AI, and multi-dimensional sustainability aligned with the SDGs in resource-scarce and institutionally fragile environments remains scarce. Empirical evidence from real post-conflict projects is also limited, restricting the applicability of existing findings.

4.1 Research Contributions

This study addresses these gaps by: 1. Proposing an integrated BIM–AI framework aligned with the SDGs to support multi-dimensional sustainability in post-conflict reconstruction. 2. Providing empirical validation through Syrian case studies, demonstrating improved environmental, social, and economic outcomes under real-world constraints. 3. Introducing an SDG-oriented sustainability assessment embedded in BIM–AI workflows, enabling measurable and transparent evaluation. 4. Advancing theoretical discourse by framing digital technologies as strategic enablers of Building Back Better, offering a transferable framework for other conflict-affected contexts.

5. CONCEPTUAL FRAMEWORK

5.1 Theoretical Foundations of the Framework

The proposed conceptual framework is grounded in three complementary theoretical foundations: sustainable development theory, digital transformation in the construction industry, and post-conflict reconstruction paradigms. Sustainable development theory emphasizes the interdependence of environmental protection, social well-being, and economic viability, particularly in contexts where resource constraints and long-term resilience are critical. Within post-conflict settings, sustainability is not merely an environmental aspiration but a strategic necessity for preventing the reproduction of pre-conflict vulnerabilities and ensuring inclusive recovery. From a digital transformation p erspective, Building Information Modeling (BIM) represents a shift from fragmented, document-based practices toward integrated, data-driven processes across the building life cycle. BIM enables the consolidation of geometric, environmental, and operational data into a unified digital environment, thereby enhancing transparency, coordination, and performance evaluation. However, BIM alone remains limited in its capacity to address complex optimization and predictive challenges inherent in sustainable reconstruction. Artificial Intelligence (AI) complements BIM by introducing advanced analytical capabilities, including pattern recognition, prediction, and optimization. AI-driven models enable the exploration of multiple design and operational scenarios, allowi ng decision-makers to assess trade-offs among environmental, social, and economic objectives. When integrated within a BIM environment, AI transforms static information models into dynamic decision-support systems capable of responding to the uncertainties and constraints typical of post-conflict reconstruction contexts.

5.2 BIM–AI–SDGs Conceptual Framework for Post-Conflict Reconstruction

Based on these theoretical foundations, this study proposes an integrated BIM–AI conceptual framework explicitly aligne d with the Sustainable Development Goals (SDGs) to support multi-dimensional sustainability in post-conflict reconstruction projects. The framework conceptualizes post-conflict conditions—such as physical destruction, resource scarcity, institutional fragility, and urgent reconstruction demands—as

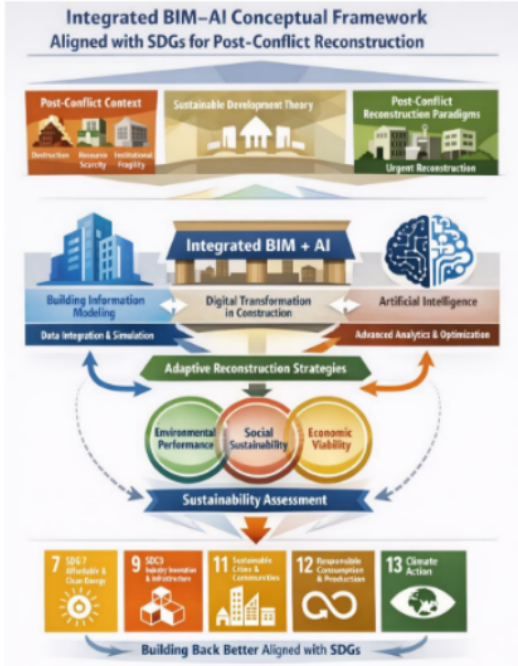

Figure 2. Integrated BIM–AI conceptual framework aligned with SDGs for post-conflict reconstruction

contextual drivers that necessitate adaptive and data-driven reconstruction strategies. Within this context, BIM and AI function as interconnected digital enablers rather than independent tools. BIM serves as the core information platform, structuring project data and enabling performance simulation across design and operational stages. AI operates as an intelligent analytical layer embedded within the BIM environment, enhancing its capability to optimize energy pe rformance, predict operational behavior, and evaluate sustainability trade-offs. The integration of BIM and AI facilitates the systematic assessment of sustainability outcomes across three interrelated dimensions: environmental performance (e.g., energy ef ficiency, emissions reduction), social sustainability (e.g., indoor comfort, user well-being, community acceptance), and economic viability (e.g., life-cycle cost efficiency, payback periods). These outcomes are explicitly mapped to relevant SDGs, particularly SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). By aligning digital decision-support processes with SDG-oriented sustainability objectives, the proposed framework operationalizes the principles of Building Back Better within post-conflict reconstruction. Rather than treating sustainability as an abstract goal, the framework embeds it within mea surable, data-driven workflows that support resilient, inclusive, and resource-efficient reconstruction strategies applicable to conflict-affected and resource-constrained contexts. Reconstruction

6. METHODOLOGY

6.1 Research Design

This study adopts an exploratory–explanatory case study research design to investigate the effectiveness of integrating Building Information Modeling (BIM) and Artificial Intelligence (AI) in enhancing multi-dimensional sustainability within post-conflict reconstruction contexts. The case study approach is particularly suitable for this research due to the complexity of post-conflict environments, where contextual factors such as resource scarcity, institutional fragility, and socio-economic constraints significantly influence reconstruction outcomes. By combining quantitative performance simulations with data-driven optimization and qualitative sustainability interpretation, the methodology enables an in-depthexamination of how the proposed BIM–AI conceptual framework operates under real-world reconstruction conditions. This mixed analytical approach aligns with previous methodological recommendations for studying digital innovation and sustainability in complex and uncertain contexts.

6.2 Case Study Context and Selection

Two complementary case studies from Syria were selected to empirically validate the proposed framework. Syria represents a critical and contemporary post-conflict context characterized by extensive urbandestruction, energy shortages, and urgent reconstruction demands, making it a representative setting for investigating sustainable reconstruction strategies. The first case study focuses on a service building located in the coastal city of Tartous , selected to evaluate the environmental and energy-related performance of BIM–AI integration at the building scale. This case enables detailed simulation and optimization of energy consumption, system efficiency, and operational performance. The second case study examines the reconstruction of the Al-Qarabis neighborhood in Homs, a heavily damaged urban area, selected to assess the broader social and economic implications of BIM-supported sustainable reconstruction at the neighborhood scale. Together, these cases provide multi-scalar empirical evidence, strengthening the generalizability of the framework across different reconstruction typologies.

6.3 BIM Modeling and Data Preparation

For both case studies, detailed BIM models were developed to represent architectural, structural, and building services components. The BIM environment served as the central data repository , integrating geometric information with material properties, system specifications, occupancy patterns, and climatic data. In the Tartous case study, the BIM model was configured to support energy performance simulation, including building envelope charac teristics, HVAC systems, lighting configurations, and operational schedules. Climate data representative of the local coastal environment were incorporated to ensure realistic simulation conditions. In the Al-Qarabis reconstruction case, BIM models were us ed to represent urban blocks, housing typologies, infrastructure networks, and service facilities. Sustainability-related parameters, such as material selection, density, and spatial configuration, were embedded within the models to enable comparative evaluation of reconstruction scenarios.

6.4 Artificial Intelligence Integration and Optimization Workflow

Artificial Intelligence techniques were integrated within the BIM workflow to enhance analytical and decision-support capabilities. AI models were develop ed using Python-based analytical tools to process simulation outputs, identify dominant performance drivers, and generate optimized scenarios. In the building-scale case study, AI algorithms were applied to analyze energy consumption patterns, evaluate the sensitivity of performance variables, and optimize system configurations related to cooling loads, lighting efficiency, and renewable energy integration. The AI layer enabled the exploration of multiple design and operational scenarios beyond the limitations of conventional parametric simulations. Rather than operating as an external analytical tool, AI was embedded within the BIM-based workflow, allowing iterative feedback between model adjustments and performance evaluation. This integration transformed the BIM environment from a static representation into a dynamic, data-driven decision-support system aligned with sustainability objectives.

6.5 Sustainability Indicators and SDGs Mapping

To assess multi-dimensional sustainability, a set of environmental, social, and economic indicators was defined based on established sustainability assessment frameworks and post-conflict reconstruction literature. Environmental indicators included energy consumption, system efficiency, and emissions-related performance. S ocial indicators focused on indoor environmental quality, user comfort, and spatial adequacy, while economic indicators addressed life-cycle cost efficiency and payback periods. These indicators were systematically mapped to relevant Sustainable Developmen t Goals (SDGs), particularly SDG 7, SDG 9, SDG 11, SDG 12, and SDG 13. The mapping process ensured that sustainability assessment outcomes were not treated as isolated performance metrics but as contributions to broader global development objectives. By em bedding SDG-oriented indicators within the BIM–AI workflow, the methodology enabled a transparent and measurable evaluation of sustainability outcomes in post-conflict reconstruction projects.

6.6 Data Analysis and Validation

Simulation outputs and AI-generated results were analyzed through comparative assessment of baseline and optimized scenarios. Performance improvements were quantified across environmental, social, and economic dimensions, allowing for the evaluation of trade-offs and synergies among su stainability objectives. Validation was achieved through cross-comparison between BIM simulation results, AI optimization outputs, and reconstruction constraints documented in the case study contexts. This triangulation enhanced the robustness of the findi ngs and supported the reliability of the proposed framework under post-conflict conditions.

7. CASE STUDY AND RESULTS

7.1 Overview of the Case Studies

To empirically validate the proposed BIM–AI–SDGs conceptual framework, two applied case studies from Syria were analyzed, representing distinct yet complementary post-conflict reconstruction contexts. The selection of these cases was guided by their relevance to urgent reconstruction needs, availability of baseline data, and their potential to demonstrate sustainability trade-offs under severe resource and institutional constraints. The first case study examines a service building in Tartous, selected to evaluate building-scale environmental and operational performance. This case focuses primarily on energ y consumption, system efficiency, and operational optimization, making it suitable for testing the effectiveness of BIM–AI integration in improving environmental sustainability outcomes. The second case study investigates the reconstruction of the Al-Qarabis neighborhood in Homs, one of the areas most affected by urbandestruction. This neighborhood-scale case enables the assessment of broader social and economic sustainability dimensions, including spatial adequacy, infrastructure efficiency, and life-cycle cost implications. Together, the two case studies provide multi-scalar empirical evidence for evaluating the robustness and transferability of the proposed framework in post-conflict settings.

7.2 Building-Scale Case Study: Service Building in Tartous

7.2.1 Baseline BIM-Based Performance Assessment

A detailed BIM model of the service building was developed to represent architectural layout, envelope properties, mechanical systems, lighting configurations, and occupancy schedules. Baseline energy simulations revealed high operational energy demand, primarily driven by inefficient cooling systems, limited thermal insulation, and suboptimal lighting performance—conditions commonly observed in post-conflict reconstruction projects where immediate functionality often outweighs performance optimization. The baseline scenario demonstrated limited alignment with sustainability objectives, particularly in relation to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). While BIM enabled accurate quantification of energy consumption and system inefficiencies, the analysis remained largely descriptive, highlighting the limitations of BIM-only approaches in addressing complex optimization challenges. assessment.

7.2.2 AI-Driven Optimization and Performance Improvements

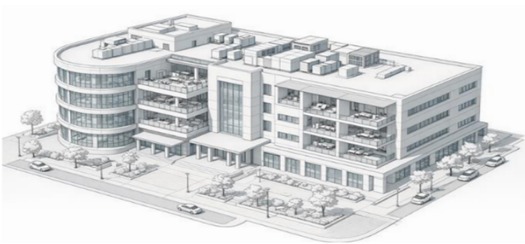

Figure 3. BIM-based 3D model of the service building in Tartous used for baseline performance assessment

To overcome these limitations, AI-based optimization algorithms were integrated within the BIM workflow. The AI layer processed simulation outputs and explored multiple design and operational scenarios, focusing on HVAC system configurations, envelope performance parameters, and lighting efficiency. The optimized scenarios achieved measurable reductions in annual energy consumption and peak cooling loads, demonstrating the capacity of AI to identify non-linear relationships and performance drivers that are not readily captured through conventional parametric simulations. These improvements directly contributed to enhanced environmental performance and operational efficiency, reinforcing the role of AI as a critical enabler of performance-driven decision-making. From a sustainability perspective, the optimized outcomes showed clear contributions to SDG 7 through improved energy efficiency and reduced reliance on conventional energy sources, and to SDG 9 (Industry, Innovation and Infrastructure) by demonstrating the application of innovative digital technologies within constrained reconstruction contexts.

7.3 Neighborhood-Scale Case Study: Al-Qarabis Reconstruction in Homs

7.3.1 Baseline Reconstruction Scenario

At the neighborhood scale, BIM models were developed to represent housing typologies, urban blocks, infrastructure networks, and service facilities. The baseline reconstruction scenario reflected typical post-conflict priorities, emphasizing rapid rebuilding and cost minimization. While this approach addressed immediate housing shortages, it resulted in suboptimal spatial layouts, inefficient infrastructure distribution, and limited consideration of long-term sustainability. Social sustainability challenges were particularly evident, including inadequate indoor environmental quality, limited public space provision, and weak integration of community needs. Economically, the baseline scenario exhibited high projected life-cycle costs due to inefficient material use and infrastructure redundancy. within the city of Homs. the city of Homs.

7.3.2 BIM–AI-Supported Scenario Evaluation

Figure 4. High-resolution satellite image illustrating the condition of the neighborhood prior to 2011 within the city of Homs

Figure 5. High-resolution satellite image illustrating the condition of the neighborhood after 2011 within the city of Homs

The integration of AI within the BIM-based neighborhood model enabled the evaluation of alternati ve reconstruction scenarios that balanced environmental, social, and economic objectives. AI-driven analysis supported the optimization of housing density, spatial configuration, and infrastructure layout, allowing for comparative assessment of multiple reconstruction strategies. Results indicated notable improvements in spatial efficiency, infrastructure utilization, and life-cycle cost performance. Social sustainability indicators, including indoor comfort and spatial adequacy, showed measurable enhanceme nt, supporting alignment with SDG 11 (Sustainable Cities and Communities). Economically, optimized scenarios demonstrated improved cost efficiency and reduced long-term maintenance burdens, contributing to SDG 12 (Responsible Consumption and Production). Importantly, the BIM–AI workflow enabled transparent evaluation of trade-offs between competing sustainability objectives, supporting informed decision-making under post-conflict constraints.

7.4 Cross-Case Comparative Results

A comparative analysis of the two case studies highlights the scalability and adaptability of the proposed BIM–AI–SDGs framework. At the building scale, the framework proved particularly effective in optimizing environmental and operational performance, while at the neighborhood scale it demonstrated strong potential in addressing social and economic sustainability challenges. Across both cases, the explicit mapping of performance outcomes to relevant SDGs transformed sustainability assessment from a qualitative aspiration into a measur able and policy-relevant process. This alignment strengthened the analytical rigor of the study and enhanced the relevance of the findings for reconstruction agencies and policymakers operating in post-conflict environments.

The case study results provide empirical evidence that integrating BIM and AI within an SDG-oriented conceptual framework can significantly enhance sustainability outcomes in post-conflict reconstruction projects. Rather than treating digital tools as isolated technical solutions, the findings demonstrate their potential as strategic enablers of Building Back Better, capable of supporting resilient, inclusive, and resource-efficient reconstruction. By grounding the analysis in real post-conflict contexts, the study addresses a critical gap in the literature and offers a transferable methodological approach applicable to other conflict-affected and resource-constrained regions. The results underscore the necessity of moving beyond conventional reconstruction practices toward data-driven, sustainability-oriented decision-support systems that align local reconstruction efforts with global development agendas.

Table 7. BIM–AI-enabled sustainability outcomes aligned with SDGs

Sustainability Dimension	BIM–AI Application Outcome	Measured / Observed Improvement	Relevant SDGs	Contribution to Post-Conflict Reconstruction
Environmental Sustainability	BIM-based energy modeling integrated with AI-driven optimization	Reduction in operational energy demand and improved system efficiency compared to baseline scenarios	SDG 7 (Affordable and Clean Energy)	Supports energy security in post-conflict contexts characterized by fuel shortages and unstable supply
Environmental Sustainability	AI-assisted evaluation of envelope and system configurations within BIM	Improved thermal performance and reduced cooling loads under local climatic conditions	SDG 13 (Climate Action)	Mitigates long-term environmental impact while adapting reconstruction to climate-sensitive regions
Economic Sustainability	BIM-enabled life-cycle cost analysis enhanced through AI optimization	Lower life-cycle costs and improved cost–performance balance despite limited financial resources	SDG 9 (Industry, Innovation and Infrastructure)	Enhances economic feasibility and resilience of reconstruction investments
Economic Sustainability	Scenario-based optimization of design and operational alternatives	More efficient allocation of materials and systems under post-conflict resource constraints	SDG 12 (Responsible Consumption and Production)	Reduces material waste and supports responsible reconstruction practices
Social Sustainability	BIM-supported assessment of indoor environmental quality indicators	Improved indoor comfort and spatial adequacy for users	SDG 11 (Sustainable Cities and Communities)	Contributes to healthier and more inclusive living and service environments in reconstructed areas
Decision-Making and Governance	Integrated BIM–AI decision-support workflow aligned with sustainability indicators	More transparent, data-driven decision-making across design and reconstruction stages	SDG 9 (Industry, Innovation and Infrastructure) and SDG 11	Strengthens institutional decision-making capacity in fragile post-conflict settings
Multi-Dimensional Sustainability	Explicit mapping of BIM–AI performance indicators to SDGs	Clear linkage between technical performance and global sustainability objectives	SDG 7, 9, 11, 12, 13	Operationalizes SDGs within real reconstruction projects rather than treating them as abstract goals

8. DISCUSSION

This section discusses the implications of the empirical findings in relation to existing literature on post-conflict reconstruction, digital construction technologies, and sustainability frameworks. The discussion is structured around three interrelated themes: multi-dimensional sustainability enhancement, the role of BIM–AI integration in post-conflict decision-making, and alignment with global development agendas.

8.1 BIM–AI Integration and Multi-Dimensional Sustainability

The results demonstrate that integrating BIM and AI within post-conflict reconstruction projects can significantly enhance sustainability outcomes across environmental, economic, and social dimensions. Unlike conventional BIM-based approaches that primarily support visualization and static performance assessment, the integration of AI introduced adaptive optimization capabilities, enabling the exploration of multiple design and operational scenarios under severe resource constraints. This finding directly addresses limitations identified in previous studies, which highlighted BIM's restricted capacity to handle complex, multi-objective optimization problems in sustainability-driven design. From an environmental perspective, the observed improvements in energy performance and system efficiency confirm the effectiveness of BIM–AI workflows in supporting SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). These outcomes are particularly significant in post-conflict contexts such as Syria, where energy shortages and unstable supply systems exacerbate vulnerability. The ability to optimize energy demand at early design and reconstruction stages contributes to long-term environmental resilience rather than short-term recovery alone. Economically, the results indicate that BIM–AI integration supports more efficient allocation of limited financial and material resources, aligning with SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production). By embedding life-cycle cost considerations within AI-driven optimization processes, the framework moves beyond initial cost minimization toward long-term economic viability. These finding challenges prevailing reconstruction practices that prioritize rapid delivery at the expense of future operational burdens. Social sustainability outcomes, while less frequently quantified in digital construction research, emerged as a critical dimension of the proposed framework. Improvements in indoor env ironmental quality and spatial adequacy support SDG 11 (Sustainable Cities and Communities), reinforcing the argument that post-conflict reconstruction should address human well-being alongside physical rebuilding. The results demonstrate that digital tool s can meaningfully contribute to social objectives when explicitly embedded within sustainability-oriented decision-support systems.

8.2 Implications for Post-Conflict Reconstruction Practice

The findings contribute to post-conflict reconstruction literature by demonstrating how digital technologies can operationalize the principles of Building Back Better (BBB). While BBB is widely endorsed at the policy level, its practical implementation often remains ambiguous due to the absence of measurable tools and indicators. The proposed BIM–AI framework addresses this limitation by translating abstract sustainability principles into data-driven, performance-based workflows applicable under post-conflict constraints. Importantly, the case studies illustrate that BIM–AI integration enhances transparency and consistency in decision-making, even in contexts characterized by institutional fragility. By centralizing project information within a BIM environment and augmenting it with AI-driven analysis, reconstruction stakeholders are better equipped to evaluate trade-offs between speed, cost, and sustainability. This supports recent calls in the literature for evidence-based decision-support systems tailored to fragile and conflict-affected environments. Moreover, the multi-scalar application of the framework—spanning building-and neighborhood-level case studies—suggests its potential transferability across different reconstruction typologies. This scalability is particularly relevant for post-conflict contexts, where reconstruction efforts often range from individual service buildings to large-scale urban regeneration initiatives.

8.3 Alignment with Sustainable Development Goals

A key contribution of this study lies in establishing an explicit and measurable linkage between BIM–AI integration outcomes and the Sustainable Development Goals. Unlike prior research that references SDGs at a conceptual level, the results demonstrate how digital performance indicators can be systematically mapped to specific SDGs. This alignment enhances the strategic relevance of digital construction research for policymakers, international organizations, and reconstruction agencies operating in post-conflict contexts. By embedding SDG-oriented indicators within BIM–AI workflows, the framework enables sustainability assessment to move beyond symbolic compliance toward operational accountability. This approach strengthens the role of digital technologies as instruments of sustainable development rather than purely technical solutions, addressing a critical gap identified in both sustainability and post-conflict reconstruction literature.

9. CONCLUSION

This study investigated the potential of integrating Building Information Modeling (BIM) and Artificial Intelligence (AI) to enhance multi-dimensional sustainability in post-conflict reconstruction projects, using Syria as an empirical case study. The research responds to a critical gap in the literature by bridging digital construction technologies, sustainability frameworks, and post-conflict reconstruction practices within a unified conceptual and methodological framework. The findings demonstrate that BIM–AI integration can significantly i mprove e nvironmental p erformance, economic efficiency, and social sustainability when explicitly aligned wi th the Sustainable Development Goals. By transforming BIM from a static information repository into a dynamic, AI-enhanced decision-support system, the proposed framework enables data-driven optimization and informed trade-off analysis under severe post-conflict constraints. This capability is particularly valuable in contexts characterized by resource scarcity, institutional fragility, and urgent reconstruction demands. The study contributes theoretically by advancing the discourse on sustainable post-conflict reconstruction through an operationalized interpretation of Building Back Better. Methodologically, it introduces an SDG-oriented assessment approach embedded within BIM–AI workflows, enabling measurable and transparent evaluation of sustainability outcomes. Empirically, the applied case studies provide rare real-world evidence from a post-conflict context, strengthening the validity and transferability of the proposed framework. Overall, the research demonstrates that digital technologies, when strategically integrated and aligned with global sustainability agendas, can play a transformative role in shaping more resilient, inclusive, and sustainable post-conflict reconstruction trajectories. The proposed BIM–AI–SDGs framework offers a practical and adaptable foundation for future reconstruction initiatives in conflict-affected and resource-constrained regions.[14]

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