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Building Information Modelling Implementation Model for Sustainable Building Projects in Developing Countries: A PLS-SEM Approach

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Abstract: When building homes, sustainability principles should be followed throughout the process to achieve maximum advantages. Building information modeling (BIM) activities can aid in achieving sustainable goals. Third-world countries' building industry implements informal approaches to information dissemination through email newsletters and websites. This research seeks to provide a model for the application of BIM and its relationship with overall sustainable success (OSS) in building projects. BIM activities were identified from the literature, and a survey form was distributed to 180 professionals in the Egyptian construction industry. Partial Least Squares-Structural Equation Modeling (PLS-SEM) was used to establish the structure of BIM activities and assess their correlation with project success, revealing BIM accounts for 30% of sustainability. The study's findings inform decision-making to improve project sustainability and reduce costs by introducing BIM to developing countries' construction industries.

Keywords: sustainable success; Egypt; Structural Equation Modelling BIM; building projects

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1. Introduction

Residential housing development is essential for the quality of life and well-being of people worldwide [1]. Housing accounts for 40% of global energy consumption and one-third of greenhouse gas emissions [2,3]. However, the distribution of residential properties struggles to meet the increasing demand in our rapidly urbanizing world, making it difficult for low-income individuals to access affordable housing [4,5]. Approximately 828 million people reside in substandard housing in developing countries, and this number is expected to rise to 1.4 billion [4,6,7]. Given the crucial role of residential housing in promoting healthy living environments, the increasing economic growth in these countries has underscored the need for cost-effective housing solutions [8]. Governments have implemented affordable housing initiatives, but their accessibility to low-income earners remains uncertain [1,4]. Egypt faces challenges related to sustainability, poor working conditions, unemployment, and population growth [9–11]. The lack of suitable housing programs is a fundamental challenge for policymakers [12]. The importance of constructing sustainable buildings that prioritize resource efficiency and eco-friendliness is emphasized [13]. Transformation in the building industry through efficient and sustainable construction programs can lead to positive environmental and societal outcomes [14].

In addition, it is important to note that construction experts are unable to fully ascertain the environmental consequences of erecting buildings [15]. As a result, BIM can be effectively incorporated into the sustainability system during the design of the projects and initial phases, occupying a prominent role in any further advancements. Despite the universality of the literature on applications and methodology, they can still be integrated into a success-oriented approach throughout the entirety of the project [16]. BIM, according to Autodesk [17], is like a brainy artist that creates a 3D-based model approach, empowering engineering, architecture, and construction professionals with the knowledge and skills necessary to effectively plan, design, construct, and maintain infrastructure and structures. The fundamental inherent aspects of BIM improved construction, design, and maintenance [18,19]. BIM is continually experiencing fundamental changes in response to stakeholder sector needs for solutions to solve repeatedly recurring and systematic problems, namely problems with cost, time, and productivity management [20]. BIM as a profession is focused on repeatable manufacturing, using the most efficient technologies available to increase Return on Investment (ROI) via sophisticated and reliable procedures [21]. BIM acts as a central hub that enables plumbing, mechanical, and electrical contractors, designers, and engineers, as well as facility management firms, to implement diverse building projects of varying sizes and types [22]. Consequently, BIM has been hailed as a game-changing technology, described as a powerful tool that can transform the entire lifecycle of a project for the better [22].

Despite the widespread use of Building Information Modelling (BIM) in developed countries to address construction challenges, its adoption in developing nations, such as Egypt, has not gained comparable momentum. While BIM has made some notable inroads in Egypt, there is still a lack of comprehensive evaluation regarding its implementation approaches in construction projects within the country. This absence of standardized BIM implementation in Egypt's construction industry has led to the utilization of ad-hoc methods, resulting in poorly coordinated teamwork and increased building project costs. In light of the policies promoting environmental sustainability and the proliferation of measures and standards since 2011, it becomes crucial to incorporate the BIM standard to optimize construction processes in Egypt [23]. Furthermore, it is noteworthy that the Egyptian Authorities have set a goal to elevate the country to become one of the top 30 economies worldwide by 2030, as reported by [24]. Therefore, the integration of BIM in the development of houses in Egypt becomes a critical step toward achieving this ambitious target. As a consequence, the research question "What impact does the integration of BIM have on OSS (Overall Sustainable Success) in residential construction projects?" was derived. By examining the influence of BIM integration on OSS, researchers aim to understand the extent to which adopting BIM methodologies can enhance the overall success of residential construction projects in Egypt. This research inquiry highlights the significance of BIM as a potential solution to address the existing challenges in the construction industry and its potential to contribute to the achievement of national goals and objectives.

In an attempt to overcome this gap, this study used the partial least square (PLS) modeling method to undertake a quantitative analysis of the link between the BIM application and overall sustainable success (OSS). Additionally, this study aims to highlight the crucial factors that affect BIM application to encourage the effective adoption of sustainable building practices and investigate the fundamental connection between sustainable building practices and BIM from the standpoint of application user behavior. The concept of deliberate conduct with the implementation of BIM is combined in the present work to create a theoretical model. The findings of this research are expected to contribute to the implementation of BIM in construction projects in a manner that results in cost savings and quality improvements. This will be achieved through the provision of valuable information that aids decision-makers in adopting BIM effectively.

2. Research Model Development

2.1. BIM Activity in the Building Industry

Building Information Modeling (BIM) is a newly developed technology or technical approach that has been shown to be helpful for building projects [25]. Because most organizations have been bound to comfy zones [26], using BIM in a building project can be considered as a gradual organizational evolution [27], The majority of businesses will have to adapt to new distribution methods and new technology. The RIBA's Plan of Work (PoW) and Building Information Modeling (BIM) guidance documents, which were developed in the UK, are extensively used in Egypt and the Middle East. There have been relatively few academic papers on the experiences with the use of such BIM standards in Egypt. BIM-RIBA is an initiative that BIM and RIBA worked on together. By defining the key BIM goals and activities at each stage of the project lifecycle, the PoW was produced (Table 1) [28]. These highlight the major tasks, which have been updated to include the client's facility management and life cycle needs, as well as a statement about the expected project results, in brief. Other activities emphasize the need to establish each member of the integrated team's roles and duties early in the project. The formulation of a Project Quality Plan encompassing a detailed BIM Execution Plan and effective change control methods has been deemed an essential obligation. In order to ensure that specialized contractors can initiate performance-specified work, it is imperative that the coordination work for the BIM model is completed in ample detail during the tender stage. Consequently, several projects have been revised to reflect this need. Recent procurement techniques allow for the recruitment of these designers as members of the Integrated Team at an earlier stage. Further details on this topic will be provided in the Plan of Work review.

Table 1. BIM implementation activities in the construction industry.

Work Stage	Code	BIM Activities
Initiation	I1	Explain the value and potential implications of BIM to the customer.
	I2	Consensus on the 4D, 5D, and 6D BIM levels
	I3	Consult customers on Integrated Team mission, including expert requirements and BIM Model Manager appointment.
	I4	Establish model ownership and other long-term commitments.
	I5	Specify BIM data, outcomes, and post-occupancy evaluation.
	I6	Determine scope and order BIM reports and surveys.
Design	D1	Pre-BIM meeting.
	D2	Design Team initial model sharing for strategic analysis and evaluation of options.
	D3	The application of BIM data in evaluating environmental performance and analyzing spatial characteristics.
	D4	Recognize crucial elements of the model (such as prefabricated components) and create parametric objects at the conceptual level for each significant element.
	D5	The design team should be granted access to the BIM information.
	D6	Confirm the scope of the performance-specific work.
	D7	Integrating and exchanging data for thorough analysis and design coordination across models.
	D8	Integrating/developing generic/custom design elements
	D9	Use of BIM data for assessing the efficiency and sustainability of a given area.
	D10	Information exchange for the purpose of coordinating designs, conducting technical analyses, and incorporating new specifications.
	D11	Export planning data. 4D/5D evaluation.

Table 1. *Cont.*

Work Stage	Code	BIM Activities
Pre-Construction	P1	Convey information for use in Building Control Analysis.
	P2	Information exchange with suppliers to complete design coordination and in-depth analysis.
	P3	Comprehensive analysis, modelling, and integration.
	P4	Develop production-ready parametric objects for all key components (using tier-2 supplier data if available and applicable).
	P5	Insert requirements into a model.
	P6	Final model assessment and approval.
	P7	Provide the contractor(s) with access to the BIM model.
	P8	Integrating subcontractor performance-related work model data with the BIM model data.
	P9	Consult with the contractor on construction sequencing (4D).
Construction	C1	Establish the scope and schedule.
	C2	Final documentation and data release from the BIM.
	C3	Data from 4D/5D BIM are used for managing construction contracts.
Use	U1	Once asset modifications are done, Facilities Management BIM model data are provided.
	U2	The BIM model data contains object parametric information.

Other BIM activities have been adjusted to reflect that the design was essentially finished and that the only ongoing design effort at this time is supporting problems as they come up on-site. Each phase of the outline plan of work has a list of fundamental BIM tasks next to it as examples. This article should be read in connection with the other publications that the government and BSI are developing to specify the content of "information or Data Drops", as well as duties and responsibilities in a BIM project [29]. The Royal Institute of British Architects (RIBA) BIM Overlay to the RIBA Outline Plan of Work has established a list of BIM activities aligned with the project's life cycle in the construction industry. This list is presented in Table 1.

2.2. Overall Sustainable Success

Sustainability, a widely discussed concept in literature, has garnered significant attention, as evident from numerous publications, including notable works by researchers [30,31]. Observations made by [32] highlight the complexity surrounding the transformation of strategic sustainability procedures and project targets. Notably, scholars [30,33] emphasize the crucial need to maintain a delicate equilibrium between environmental, economic, and social factors. Within the realm of the construction industry, the advent of sustainability concepts has spurred a relentless pursuit of viable approaches to integrate these principles into existing work environments [34].

When considering the implementation of BIM during the initial operational stages, several key drivers come to the forefront. The pursuit of innovative corporate social responsibility principles geared towards enhancing sustainability, coupled with their widespread adoption by enterprises, serves as primary catalysts for facilitating BIM implementation [35]. Consequently, the incorporation of BIM into building operations warrants scrutiny through the lens of the three core dimensions of sustainability: economic, environmental, and social. This comprehensive evaluation aims to ensure that BIM aligns with the overarching sustainability goals and effectively contributes to a holistic and balanced approach to construction practices.

2.2.1. Economic

The adoption of BIM for sustainable building is often driven by the potential for economic gains. BIM facilitates the achievement of a balance between organizations' economic bottom line and sustainability goals by offering capabilities in cost estimation and risk management [36]. To ensure accurate prediction and calculation of costs for each project phase, it is recommended by [36] to divide the cost estimation, and resource needs into distinct phases. In order to enhance the effective and efficient calculation of project risks, Ref. [37] suggests that construction managers integrate time into their project breakdowns by utilizing 4D models. This step is particularly critical for cost reduction and leveraging the 3D representations provided by BIM. According to [38], the inclusion of environmental benefits, along with the prioritization of human welfare and social values in project designs, is vital in considering a project as sustainable, even if it contributes gradually and cost-effectively towards achieving project objectives. Moreover, the utilization of BIM for other project components can significantly impact cost efficiency. For example, making predictions about the future fosters discovery and strengthens cooperation among stakeholders. Additionally, it has the potential to reduce waste, save time, lower costs, and improve facility management [25,36].

2.2.2. Environmental

As the project's design evolves, BIM naturally acquires a vast amount of data essential for performance support. Designers can leverage the capabilities of BIM to evaluate building performance during the early stages of the project's design, empowering them to make informed decisions based on this evaluation. This allows for efficient assessment of design alternatives and facilitates the progression toward a more sustainable design [39]. BIM implementations typically offer diverse frameworks that enable designers to estimate various aspects of the building, such as electrical and mechanical systems, as well as the breakdown of energy and material consumption. This comprehensive data allows for the generation of detailed insights into energy and resource savings, providing valuable information for optimizing the sustainability [40]. In a similar vein, several BIM software programs, including well-known solutions such as Autodesk, Revit, and Ecotect, incorporate recognized capabilities for processing data and addressing environmental concerns within the project. These software programs not only enable efficient data management but also assist designers and architects in effectively managing resource utilization and energy consumption. They often provide specialized tools for crucial aspects of sustainable building design, such as building orientation assessment, cooling and heating load analysis, shading design, and solar path analysis. These features empower designers to make informed decisions regarding energy efficiency, occupant comfort, and overall sustainability, leading to enhanced project outcomes [40,41]. The integration of BIM into sustainable building practices goes beyond simple data visualization and extends into the realm of performance analysis and informed decision-making. By harnessing the power of BIM, designers can explore and evaluate various design options, optimize resource usage, and reduce energy consumption, ultimately contributing to the creation of more sustainable and environmentally conscious buildings [42].

2.2.3. Social

In accordance with the Western Australia Council of Social Services, Social Sustainability arises when formal and informal processes, systems, structures, and relationships actively enhance the capability of both present and future generations to establish healthy and habitable communities. Socially sustainable communities are impartial, multifarious, interconnected, and democratic and offer a satisfactory standard of living [43]. Social sustainability can enhance comfort and healthy living and is an important facet of the overall sustainability [38,43]. In the context of sustainability and BIM, social principles can be classified as independent or dependent features, with each encompassing a variety of definitions and concepts. The Pendent Social Sustainability Features are more quantitative and can be estimated with more accuracy via additional metrics that BIM can provide for other facets of the environment, like energy efficiency and lightning. Sassi [38] suggests that sustainable design can enhance the performance and health promotion of certain environmental structures, but in hazardous conditions, it can lead to health issues, such as stress. Consequently, this research has favorable general consequences that are advantageous to the whole community and society. Furthermore, there are several ways that sustainable design may help people's socioeconomic circumstances. In order to convey information, improve environmental quality, lower health risks from chemicals linked to building energy usage, and restore a district, for example, [22].

2.3. The Correlation between the Implementation of BIM on OSS

According to [44], BIM has significantly surpassed computer-aided design and revolutionized the building industry by promoting wider collaboration among project experts. BIM offers numerous benefits, such as improving scheme strategies [45], minimizing conflicts during the design phase [21], and enabling accurate estimation of cost and time for operational modifications while minimizing conflicts during the design phase [46]. Additionally, BIM promotes a multi-party approach, improves the performance supply chain throughout the project phases, facilitates risk-sharing among professionals, and enhances work flexibility [46].

Additionally, it has yielded better synchronization and collaboration among building professionals [47,48] and lesser eventualities and contingencies [49]. Noor et al. [50] highlighted several advantages of implementing BIM, for instance, the ability to quickly review multiple potential solutions and designs, improved management of changes in real-time, and enhanced evaluation of project success based on the completion of high-quality tasks. Additionally, Hoang et al. [51] contended that the implementation of BIM in construction projects leads to better teamwork, convenient access to data from a centralized repository, optimized models, increased accessibility, and greater efficiency of personnel and results. In addition, Shahinmoghadam et al. [52] stated that BIM's processes and tools already provide a variety of balances to improve building performance via intuitive analysis and modeling that is rich in graphics. According to Zhong et al. [53], BIM is considered a tool used by professionals to create management lifecycles and offers a structure for developing data-rich models. The simulations leverage the thermal and geometrical attributes of the building's elements to appraise its functionality and analyze its performance. For instance, Yoo et al. [54] asserted that the utilization of BIM in construction projects might improve MEP proficiency or building maintenance management. Consequently, In addition, the BIM process, project data, including construction typology and geometry, may be produced and utilized to influence choices [55,56]. Almukhtar et al. [57], as-built and as-in are two types of conditions that can be handled by using BIM to get an accurate model that depicts the project. According to Saka and Chan [58], the construction sector has exhibited sluggishness in embracing innovative digital technologies, such as BIM. As a result, the industry is trailing behind in terms of technological advancements and innovation. The implementation of BIM has the potential to offer several benefits for building experts, including streamlined project delivery and management and enabling better collaboration among stakeholders [59]. BIM has emerged as a proficient approach for generating, incorporating and managing related databases, encompassing significant building information to enable maintenance and operation [60].

Studies on management strategies and cost analysis have further highlighted the benefits of the BIM [59,61]. BIM can act as a catalyst for team collaboration, enabling seamless data sharing among multidisciplinary members Nieto-Julián et al. [62]. Moreover, Eastman, Eastman, Teicholz, Sacks and Liston [25] stress the significance of BIM in fostering effective communication among project participants. Stransky and Dlask [63] believe that BIM can serve as a decision-making tool during project implementation, leading to better performance. The literature highlights the importance of BIM in facilitating contracts' intelligent automation and promoting collaboration among team members, as demonstrated by the studies conducted by [64,65]. Additionally, The findings of Chahrour et al. [66] analysis suggest that BIM has the potential to significantly reduce project costs by identifying potential design clashes before the commencement of construction. As per [67,68], BIM has become an essential tool for advancing sustainable buildings, which strives to decrease the environmental influence of construction processes. The BIM-Building Lifecycle Assessment (LCA) application was evaluated by Amarasinghe and Soorige [69], who also provided concepts for accelerating BIM-LCA evaluations. The inherent envisioning capabilities of

BIM, which allow customers to preview their intended projects before beginning construction, are another significant factor in the popularity of this technology. By leveraging the advantages of BIM, the design team can nimbly tailor architectural features to meet the nuanced preferences of customers [25,59]. As a result, BIM's visual interface tool has come to be regarded as an indispensable component of the construction design process, not only for the initial design phase but also for streamlining construction methodologies and developing more effective construction techniques [70].

Natephra, Yabuki and Fukuda [70] implemented BIM to improve problem management and visualization through a web-based API. Their research indicated how BIM could anticipate obstacles and project advancement at an early stage. According to Raouf et al. [71], BIM has transformed conventional engineering project management methodologies, infusing new life into the project lifecycle. Conversely, the implementation of BIM is subject to change throughout this lifecycle and is frequently interrupted by inputs from diverse developmental stages, including design (engineers), construction (contractors), and operations (managers), selected for concision [72,73]. As a result of an initial analysis of prior studies, this investigation, as presented in Figure 1, postulated that:

Hypothesis 1. *Posit that there exists a significant correlation between BIM implementation and achieving OSS.*

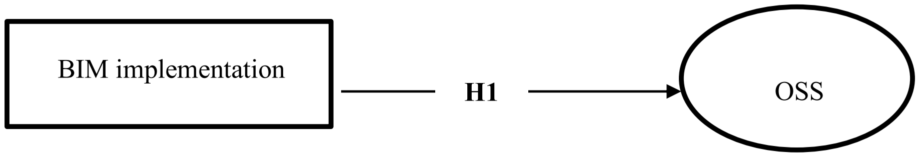

Figure 1. A theorized influence of BIM implementation activities adoption on the OSS.

3. Research Approach

This study adopts a conceptual model approach to investigate the phenomenon under consideration. A comprehensive review of the relevant literature was conducted, and the key findings were summarized to formulate hypotheses. The hypotheses were subsequently tested through empirical evidence, employing a three-phase procedure to identify, classify, and establish the connections among the constructs of the model. Figure 2 demonstrates the outcomes of the model. The model's constructs for investigating BIM's critical activities were determined through a comprehensive literature review. Table 1 illustrates BIM's critical activities. Accordingly, to investigate the influence of OSS variables and BIM activities, a systematic cross-sectional survey questionnaire was established and administered in Cairo, Egypt. Multiple stakeholders from the construction sector were recruited to participate in the study by completing the questionnaire. The questionnaire used in the study was organized into four main sections, including the Respondent's Demographic Profile, OSS factors, BIM activities, and open-ended questions. The fourth section allowed respondents to include any critical activities that were not identified in the first three sections. In order to achieve a representative sample, the authors employed a stratified sampling technique, following Ali et al. [74] recommendations. Given that the survey's focus is on BIM adoption, the use of this technique was deemed appropriate to ensure the collection of precise and dependable data. The respondents, possessing extensive BIM activity and knowledge, were evaluated using a Linkert 5-point scale, which is commonly used in earlier studies [75–80]. The scale offers response options that span from very high (5) to no or very low (1). The participants were provided with a comprehensive range of options pertaining to their experience with building projects.

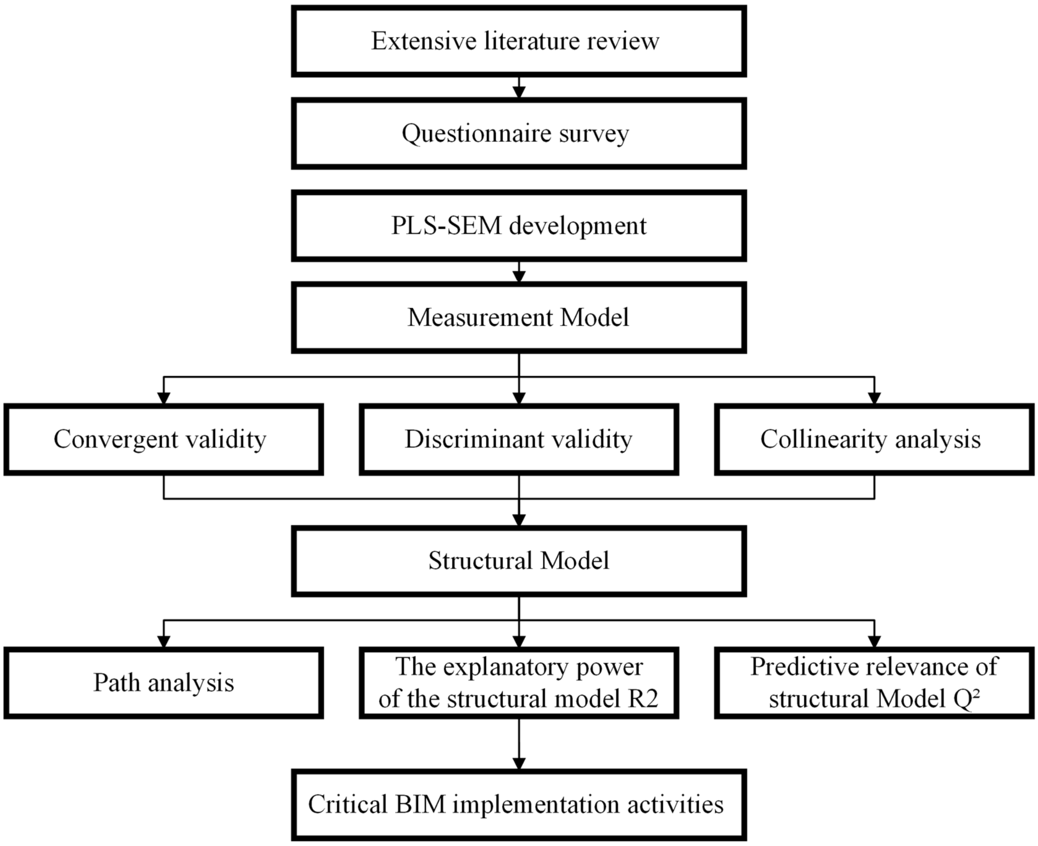

Figure 2. Research Design.

The study aimed to establish the appropriate sample size in accordance with Badewi [81]. Field [82] suggests that a minimum of 30 cases is necessary for descriptive statistical analysis, while Yin [83] recommends over 100 cases for SEM. Thus, 180 participants were chosen from a pool of 265 construction experts who completed the self-administered interview. The response rate of 67% was deemed acceptable for further analysis [84,85].

PLS-SEM Analytical Method

The study involved the analysis and comparison of four models to identify the optimal option in order to determine how BIM impacts the long-term performance of construction projects. It makes it possible to build a model for an actual building job. The techniques included System Dynamic Analysis (SDA), Multiple Linear Regression (MLR), Artificial Neural Networks (ANN), Structural Equation Modeling (SEM), and (SD). The novelty of the regression equation's use of unobserved variables, however, led to its rejection. Using the regression equation, it is a substantial limiting factor [86]. Furthermore, since the data are of a kind that has nothing to do with time, the system dynamic was not used. As a result, the study's goal is to look at OSS's adoption of BIM.

SEM is an essential methodology employed by researchers to simulate interactions among multiple constructs through specific items. The primary objective of SEM is to elucidate and validate a proposed causal theoretical model while also examining the correlation between its variables. What sets SEM apart from other modeling techniques is its ability to assess both the direct and indirect influences of hypothesized causal relationships. SEM provides a means of depicting the interrelationship between measurable and non-measurable factors in order to suit the demands of the study. Amaratunga et al. [87] claimed that the SEM approach might be used to handle mistakes inside variables. Byrne [88] asserted that the SEM has progressed to a non-experimental research technique with ambiguous hypothesis testing procedures.

In contrast, Ringle et al. [89] argued that SEM methods had gained increased recognition and prominence over time, evidenced by their publication in the MIS Quarterly journal. Moreover, Yuan et al. [90] provided that SEM is used in a social science research type. The SEM approach was used in this investigation since it is unquestionably utilized in analyses pertaining to the concentrate business. Within the field of SEM, researchers commonly utilize two distinct approaches: covariance-based SEM (CB-SEM) and component-based SEM (PLS-SEM). Notably, Ali, Elyamany, Ibrahim, Kineber and Daoud [74] assert that the component-based approach, known as Partial Least Squares SEM (PLS-SEM), is preferred over the covariance-based alternative. This preference is based on PLS-SEM's robust statistical capabilities, which enable the assessment of various parameters and the reassignment of experimental variance. Moreover, PLS-SEM demonstrates superior predictive efficacy when compared to CB-SEM.

In order to elaborate on a model and establish the relationship between OSS and BIM operations, the SEM approach was adopted in this research [91]. The relationship between OSS and BIM operations has been empirically validated using the PLS. The PLS model accounts for both formative and reflective factors in examining the connection between these two domains. As a result, it was utilized to investigate the BIM-related activities and their impact on OSS. The link between the constructs (such as the application of BIM and the experience indicators) is described by the analytical model in PLS (i.e., activities) [92].

4. Results

4.1. Analytical Model (First-Order Construct)

Figure 3 shows the conceptual framework as contained in Figure 1. The assessment of an analytical model's effectiveness, as suggested by Hair, Jr., et al. [93], mandates the careful consideration of four vital factors, such as the reliability of indicators, the reliability of constructs, the average variance extracted, and the discriminant validity. By applying the PLS algorithm and adopting Wong [94] guidelines, this study unearthed valuable insights using the following parameters:

- Weighting Scheme
- Path Weighting
- Data Metric with Mean 0 and Variance 1
- Maximum Iterations of 300
- Initial Weights of 1.0

According to Henseler et al. [95], an indicator can only be dropped from the scale if its removal leads to a significant increase in the average variance extracted (AVE) and composite reliability. In accordance with the established criteria by Ali, Elyamany, Ibrahim, Kineber and Daoud [74], variables with outer loading scores below 0.5 were excluded from this study. Figure 3 presents the outer loadings of the items in the analytical model. Consequently, the items D1, D2, D3, D9, P1, and P5 did not meet the threshold and were excluded from the model, as indicated in Table 2.

It acknowledged their less influence on related constructs. As Table 2 shows, a revised assessment was conducted after eliminating these variables due to the Cronbach alpha limits, which gauge the sensitivity of the elements involved in total. Ali et al. [96] proposed the following criteria to evaluate the internal consistency of composite reliability (CR). A value exceeding 0.7 is considered appropriate. In the case of exploratory studies, a value above 0.60 is suggested by Wong [94]. Table 2 presents the outcomes of the complete model, which surpassed the acceptable threshold (CR > 0.70) and were, thus, approved. AVE is a widely used method for evaluating convergent validity. A value exceeding 0.50 is generally considered acceptable for assessing the construct's convergent validity within the model. Ali, Elyamany, Ibrahim, Kineber and Daoud [74] recommend this value as a satisfactory convergent value. Based on the model results, all of the analyzed constructs meet this criterion.

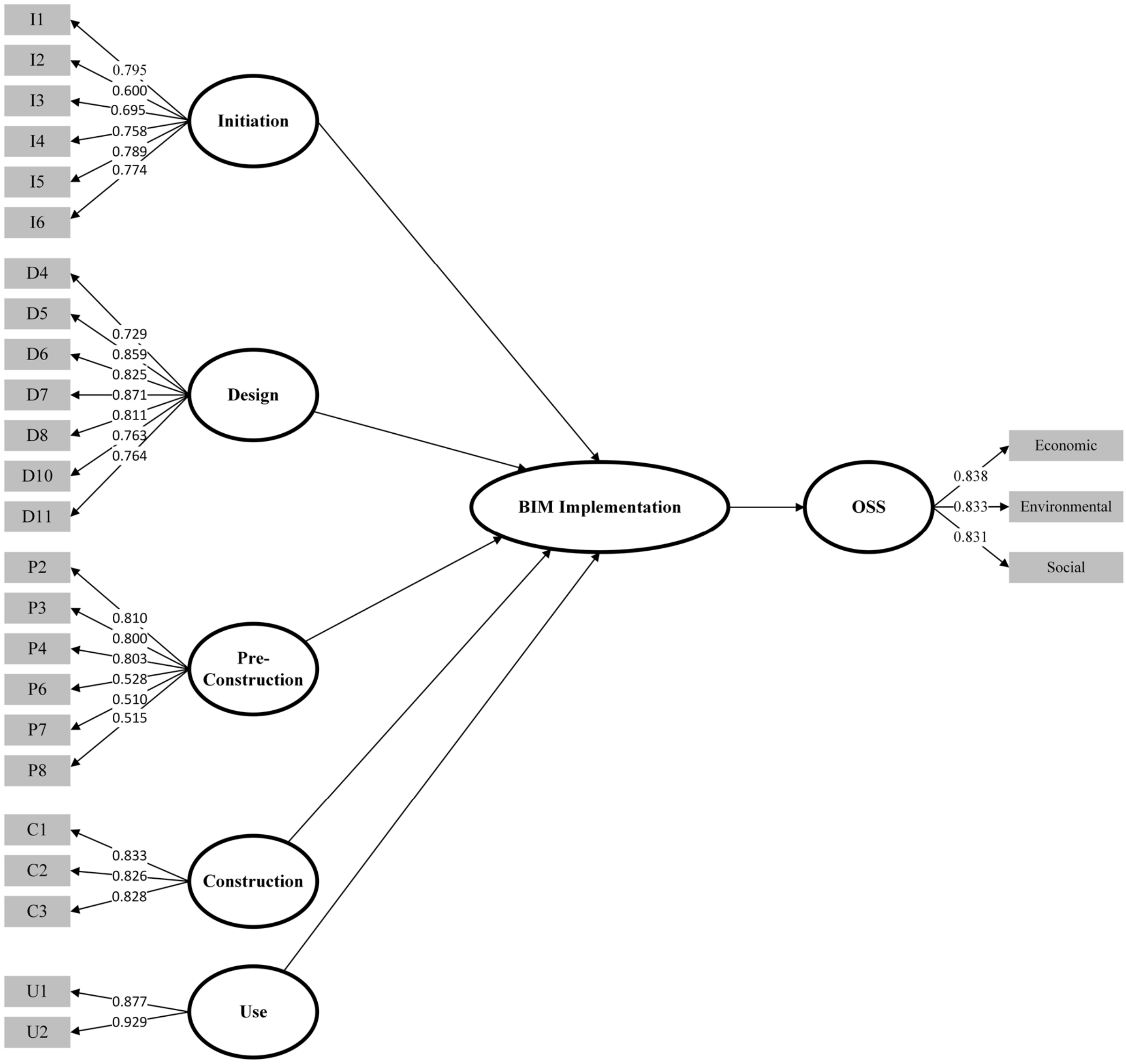

Figure 3. The PLS model.

Table 2. Results indicate convergent validity.

Constructs	Item	Outer Loading	Cronbach's Alpha	Composite Reliability	AVE
Initiation	I1	0.795	0.83	0.87	0.54
	I2	0.600			
	I3	0.695			
	I4	0.758			
	I5	0.789			
	I6	0.774			
Design	D4	0.729	0.92	0.94	0.69
	D5	0.859			
	D6	0.825			
	D7	0.871			
	D8	0.811			
	D10	0.763			
	D11	0.764			

Table 2. *Cont.*

Constructs	Item	Outer Loading	Cronbach's Alpha	Composite Reliability	AVE
Pre-Construction	P2	0.810	0.766	0.83	0.56
	P3	0.800			
	P4	0.803			
	P6	0.528			
	P7	0.510			
	P8	0.515			
Construction	C1	0.833	0.77	0.86	0.68
	C2	0.826			
	C3	0.828			
Use	U1	0.877	0.77	0.899	0.817
	U2	0.929			
OSS	Economic	0.838	0.78	0.72	0.69
	Environmental	0.833			
	Social	0.831			

Discriminant validity can be considered well-defined if the concept exhibits significant differences from other constructs based on the experimental criteria. As a result, the construct is assumed to be typical and to capture singularities that other models' constructions do not adequately detect [95]. Cross Loading Criterion and Hetrotrait-Monotrait Ratio of Correlations are two different methods for calculating the discriminant validity (DV). Individual constructs' square roots in the AVE may be correlated with any other construct that is available to study the DV. The Heterotrait-Monotrait Ratio of Correlations (HTMT) for evaluating discriminant validity. If the discriminant validity variance-based SEMs are computed exactly, the HTMT provides a unique way of assessing them and determines the precise link between dual constructs. The assessment of discriminant validity in the study employed the HTMT model, as demonstrated in Table 3. The recommended criteria by Hair et al. [97] suggest that the HTMT value should be less than 0.90 for similar constructs and less than 0.85 for different constructs. The study's constructs' HTMT values are listed in Table 4, affirming the satisfaction of the discriminant validity.

Table 3. Cross loadings results.

Items	Construction	Design	Initiation	Pre-Construction	Use	OSS
C1	**0.8327**	0.2472	0.176	0.251	0.2604	0.3222
C2	**0.8259**	0.1481	0.134	0.1572	0.278	0.2464
C3	**0.8289**	0.2586	0.081	0.3055	0.3263	0.3263
D10	0.2561	**0.7979**	0.1645	0.6865	0.1653	0.335
D11	0.2067	**0.7817**	0.1585	0.6778	0.1867	0.3379
D4	0.1298	**0.7574**	0.1229	0.563	0.1146	0.2247
D5	0.3038	**0.8738**	0.2376	0.7346	0.1965	0.3745
D6	0.2695	**0.8628**	0.2325	0.6989	0.2009	0.4095
D7	0.1857	**0.8894**	0.1791	0.7053	0.1398	0.3723
D8	0.2066	**0.8567**	0.1798	0.7569	0.193	0.3824
I1	0.0855	0.2453	**0.7955**	0.232	0.1302	0.2736
I2	0.0263	−0.0937	**0.5998**	−0.0459	0.105	0.2411
I3	0.1434	0.1587	**0.6956**	0.1718	0.055	0.2893
I4	0.0658	0.0691	**0.7571**	0.1325	0.0897	0.2836
I5	0.1208	0.2182	**0.7891**	0.2241	0.1169	0.3134
I6	0.1866	0.1692	**0.7734**	0.2213	0.4144	0.3985
P2	0.1806	0.748	0.0669	**0.8129**	0.0721	0.2375
P3	0.1392	0.7773	0.0478	**0.8093**	0.041	0.2661
P4	0.2014	0.8083	0.1836	**0.8212**	0.1272	0.3134
P6	0.1837	0.2499	0.2805	**0.5365**	0.176	0.2927
P7	0.34	0.2717	0.3789	**0.5135**	0.2473	0.2916
P8	0.2553	0.2203	0.2361	**0.5191**	0.2115	0.2467

Table 3. *Cont.*

Items	Construction	Design	Initiation	Pre-Construction	Use	OSS
U1	0.2315	0.1808	0.1915	0.137	**0.8782**	0.1802
U2	0.3814	0.1927	0.209	0.1931	**0.9288**	0.3476
Social	0.4623	0.2883	0.3603	0.1843	0.3146	**0.8306**
Economic	0.2702	0.3696	0.2525	0.3419	0.292	**0.8376**
Environmental	0.3551	0.3253	0.3939	0.3239	0.2823	**0.8339**

Table 4. HTMT values.

Factor	Construction	Design	Initiation	OSS	Pre-Construction
Construction					
Design	0.307				
Initiation	0.1835	0.2452			
OSS	0.4617	0.4922	0.4977		
Pre-Construction	0.4028	0.8278	0.3873	0.5229	
Use	0.4341	0.2417	0.2521	0.3742	0.2715

The third approach used in this analysis to examine discriminant validity was the cross-loading criterion. This method evaluates the loading of items on a particular underlying construct. The loading score above the other constructs per row must be more impressive. Table 3 revealed that the loading score for each indicator's assigned latent construct was higher than the cross-loading across the remaining model's constructs per row. Therefore, it was concluded that each construct was significantly one-dimensional.

4.2. Measurement Model (Second-Order Construct)

The bootstrap method was utilized to evaluate the significance of the first-order latent variables. This was done as the primary variable, which in BIM implementation was serving as a second-order latent variable. Notably, the success of the project represented a reflective construct, while the inclusion of formative served as one of the constructs employed in the BIM implementation. High correlations between the variables in formative measurement models are often not expected in the majority of situations. Furthermore, collinearity is questionable because of the close relationship between formative factors [98]. By analyzing the value of the Variance inflation factor (VIF), the research looked at the collinearity between the construct's defining characteristics. Internal VIF values were used to look at collinearity issues while dealing with reflective-formative second-order constructs. Five first-order BIM subscales were found to have a substantial standard path coefficient (outer weight). The maximum exterior loading on the buildings was noted, as indicated in Table 2. As presented in Table 5, the findings reveal that all VIF values were found to be below 3.5. The implication is that each of the subdomains examined in this research significantly contributes to the higher-order construct. The path coefficient, represented by the β-value, is utilized to indicate the strength of the correlation between two constructs in the model. Conversely, the path coefficient associated with the *p*-value represents the probability level at which the collected data are expected to occur by random chance. Both coefficients must meet certain thresholds: the β-value should be greater than 0.1, while the *p*-value should be less than 0.05 [99]. Therefore, as shown in Table 5, both path coefficients have met their respective thresholds.

Table 5. Second-order model results.

Path	*β*	*p*-Values	VIF
Construction -> BIM Implementation	0.154	<0.001	1.21
Design -> BIM Implementation	0.525	<0.001	2.2
Initiation -> BIM Implementation	0.222	<0.001	1.1
Pre-Construction -> BIM Implementation	0.336	<0.001	3.1
Use -> BIM Implementation	0.285	<0.001	1.19

4.3. Structural Model (Path Analysis)

An example of a linear regression model is path analysis (PA). For social management sciences, it is the perfect measuring technique. As a result, it is crucial to concurrently assess all-composite connections [100]. Applying the SEM was the first stage in the STEM analytical process. The correlation between the study constructs may be assessed using the SEM. The SEM is the crucial stage after model fitting in the SEM analysis. The SEM may be utilized after determining the correlations between the variables. The correlations between variables are well addressed in the SEM. The information showed that independent and exogenous factors were correlated [101,102]. The total model fit, with scores for the theoretical parameters coming in second, followed by size, relevance, and direction, is the primary metric used to assess the structural model [101]. The final step involved validating the analytical relationship that was formulated and built upon the study hypothesis, as depicted in Figure 1. On the other hand, SEM was used for the research hypothesis. PLS-SEM was used to assess the impact of integrating BIM on OSS based on the study methodology provided by this model. Figure 4 depicts the related research theory model. The crucial hypothesis's context and the bootstrapping method's context were evaluated. The bootstrapping procedure creates fresh samples of a size similar to the initial data set using the randomly resampled original data set. This method evaluates the validity, statistical significance, and estimated path coefficients error of the data set [103]. The standardized route coefficients, *p*-values, R2 values, and pathway significance for each internal construct were evaluated, as shown in Figure 4. Each path's *p*-values are disclosed. The results demonstrated that the BIM activities had a statistically significant influence on OSS. Additionally, the results demonstrated that BIM activities had a substantial and advantageous influence on project success ($\beta = 0.549$, $p < 0.001$).

4.4. Superiority of the Structural Model

The obtained results provide evidence regarding the dependability of each item, as well as the convergent and discriminant validity of the analytical model. The variation of the dependent variable that the structural model described was examined to gauge its exploratory power. The PLS-SEM method supported squared multiple (R^2) correlations for the dependent variable. The popular PLS approach resembled traditional regression [104]. The total variance is best shown by the R^2 value. The independent variables included inside the dependent variable characterized it. As a result, a higher value of R^2 increases the structural model's ability for prediction. The Smart PLS technique was used to obtain the R^2 values for this investigation. As a crucial dependent variable in this model, the success of initiatives had an adjusted R^2 of 0.302. It indicated that the BIM application, which was the underlying external variable, was responsible for 30.2% of the project's success. According to Chin [103], a modest degree of BIM implementation should be used.

4.5. The Structural Model Predictive Weight

The assessment of analytical importance through a structural model is a critical step in the model validation process. Blindfolding is a technique used in PLS-SEM to assess the predictive relevance of the model's constructs and validate the estimates for the dependent variables. The findings demonstrate that the project's effectiveness and success were evidenced by the Q^2 value, which achieved a score equal to 0.21, which exceeded zero.

Therefore, the model has strong relevance. It indicated that the dependent variable, which was the subject of this study's analysis, had an analytical value [105].

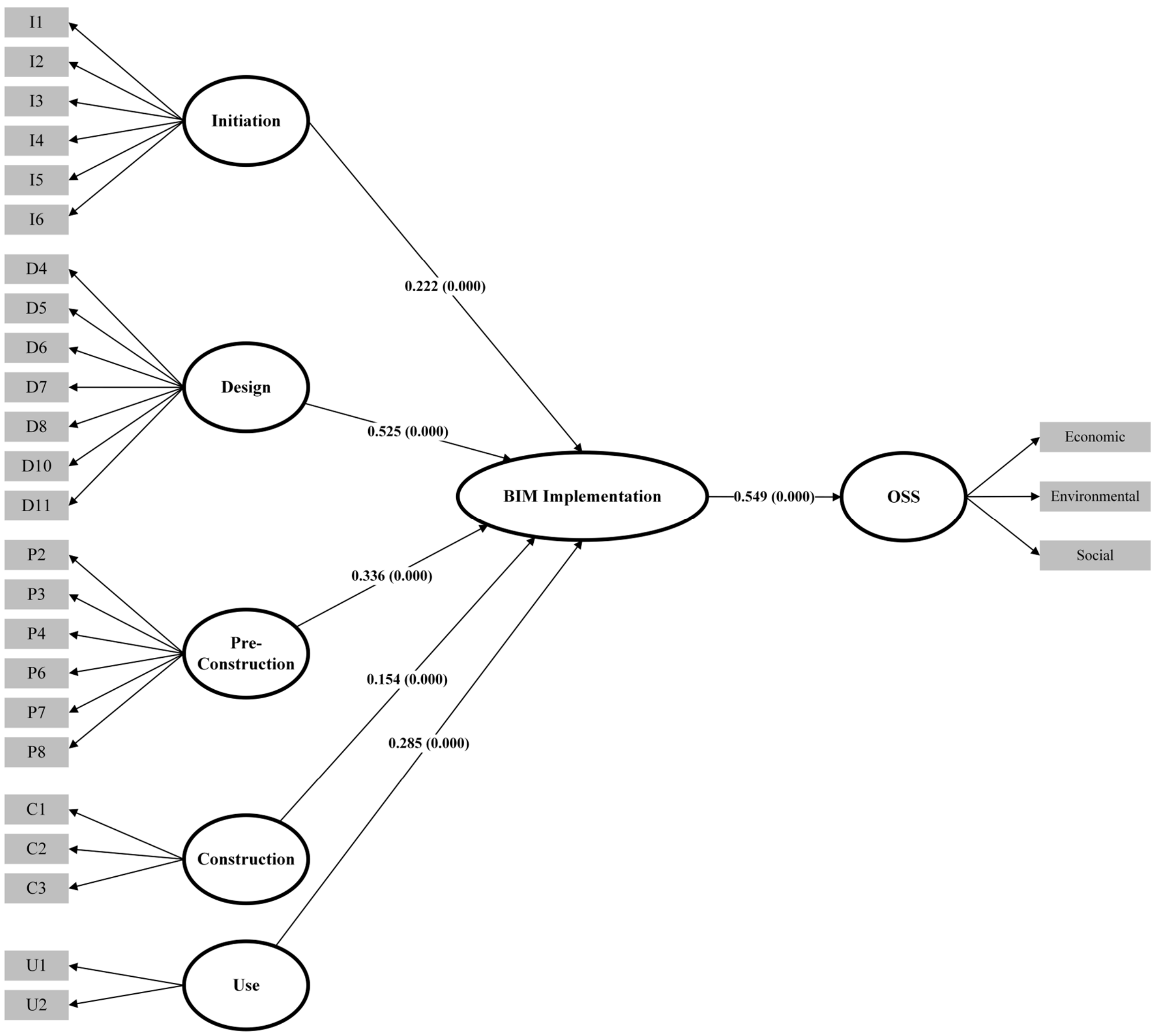

Figure 4. Bootstrapping analysis.

5. Discussion

The use of BIM by consultants and their crucial operations may greatly increase its success. Reviewing PLS-SEM models and the findings generated through looking at those models provides a strong foundation for analyzing relationships among the models involved. During the review and analysis procedures, certain significant outcomes become clear.

The PLS-SEM conducted an examination of the correlation between the model constructs, namely BIM implementation and OSS, in a sequential order of influence. The findings highlighted the significant impact of BIM implementation activities, such as Initiation, Pre-Construction, Design, and Use, on the OSS of construction projects. The study results demonstrated that the incorporation of BIM implementation could result in a significant improvement of 30.2% in the OSS. Thus, it can be inferred that BIM execution is significantly related to enhancing the success of OSS. Ghaffarianhoseini et al. [106] proposed that BIM is an established decision-making method that enables designers to assess multiple aspects of designs, such as cost, energy, and emissions. Ibem et al. [107] showed that BIM adoption enhances successful visualization for consumer design endorsement. BIM, however, is not a universal answer to every issue facing the construction sector.

Instead, it is increasingly becoming a part of Industry 4.0, a larger idea that refers to a greater convergence of the digital technology [108]. Therefore, the implementation of BIM could stimulate the construction stakeholders to understand how OSS can be boosted. The requirement for key industry participants to comprehend how to handle BIM processes and recognize the possibilities for extra enhanced accessibility, upkeep, and BIM data exchange was nevertheless established by Sidani et al. [109]. Additionally, "a suite of sophisticated project management tools is now provided by the internet of things, artificial intelligence, big data analytics, sensor-based technologies, and other technologies are networked to give improved insight and understanding of intricate contemporary projects" [110]. Economic construction implies enhancing the project's cash flow through spending money efficiently. The model results demonstrate that the economic factor had the highest loading score at 0.838. These findings corroborate the research conducted by Olanrewaju et al. [110], which showed that BIM implementation could enhance project design and visualization, leading to cost savings without sacrificing quality. Chahrour, Hafeez, Ahmad, Sulieman, Dawood, Rodriguez-Trejo, Kassem, Naji and Dawood [66] articulated that cost savings can be derived from BIM adoption through early detection of clashes in design before project implementation. Moreover, the implementation of BIM has the potential to streamline the contract process and promote effective collaboration among workers [64,65]. Additionally, BIM implementation has been found to aid in facility management and maintenance of MEP elements in construction projects.

The environmental factor was found to have the second-highest outer loading score at 0.833, following the economic factor. BIM is considered a crucial technology for achieving environmental sustainability in building and construction, particularly through the use of "Green BIM", which aims to minimize the environmental impact of building activities. This concept has been explored in the previous studies [67,68]. The empirical study conducted by Lin and Hsu [111] revealed that the adoption of BIM technology has a positive impact on construction project management and visualization through a web-based API. The findings of the study suggest that BIM has the capacity to effectively visualize complex construction processes and project progress from the early stages. Furthermore, the integration of BIM technology is crucial in the construction industry, as it offers a powerful visualization capability that enables clients to preview their proposed structures before actual construction commences. This visual feedback loop allows for early detection of potential design errors, facilitating modification to meet the client's expectations [25,59]. The work of Amarasinghe and Soorige [69] showcased the utilization of BIM in building Life-Cycle Assessment (LCA) and offered recommendations for improving BIM-LCA measurements. The social factor was ranked third in the factor analysis, with an outer loading score of 0.831. In a similar vein, Alaloul et al. [112] argued that both technical and social factors are critical determinants of the successful implementation of BIM technology.

6. Conclusions

The necessity to improve the quality of construction projects in emerging nations, particularly in the Egyptian building sector, is universally acknowledged in the literature. This study suggests that the adoption of BIM technology in construction operations can serve as a practical approach to reducing risks and enhancing sustainability. Despite its potential benefits, the adoption of BIM technology among building industry stakeholders in developing nations is limited. In order to perform this research, a questionnaire was distributed in Egypt. Experts from Egypt's construction sector were consulted for the research, which used the PLS-SEM approach to provide an analytically proven model. The model's output provided invaluable insight into the use of BIM to ensure the project's sustainability within the Egyptian construction sector. The findings of the study unveiled that the BIM activity with the most significant positive impact on Overall Sustainable Success (OSS) in sustainable building projects was Design, as demonstrated by the β-value of 0.525. On the other hand, the impact of Construction on OSS was relatively minor, with a β-value of 0.154. Moreover, the results of the study provided support for the hypothesis, emphasizing the foundational influence of BIM implementation on OSS, explaining 30.2% of the variance. This signifies a moderate level of explanatory power. The model's outcomes may save costs and improve construction success in Egypt and other poor countries. The results of this study also assist designers in understanding the benefits of maintaining BM processes to produce buildings that delight clients and boost their faith in the construction industry. Although the results are specific to BIM implementation assessments in Egypt, they may have applicability to other developing nations with similar characteristics where similar studies have not been conducted.

6.1. Theoretical and Practical Implications

The model that has been established places significant emphasis on the implementation of BIM, particularly in developing nations where there are numerous uncertainties. Furthermore, the model highlights the key activities involved in BIM implementation. To facilitate the adoption of BIM in the construction industry, government agencies and policymakers may need to offer assistance to the recognized initiatives. This would aid in creating a robust action plan to promote BIM adoption. This study was performed with the aim of assessing the link between BIM activities and project sustainability in the Egyptian construction industry.

First, this research evaluated all the key BIM adoption-related actions in the construction sector. Future analysis of BIM adoption in the building sector will be built on the findings of this study. In order to enhance appropriateness in construction projects, the hypothetical structures that emerge from this research provide a scientific foundation for determining the BIM implementation actions that must be adopted. Furthermore, this study has made various empirical and conceptual contributions to the research area.

- By discovering and conceiving more ideas inside the conceptual framework, this research adds to the theory. These are the results of OSS's deployment of BIM.
- Research on BIM implementation is widely available in developed countries; however, it is scarce in poor ones like Egypt. By analyzing the crucial steps in using BIM to improve sustainability in construction, our research has reduced this gap. The outcome of this research is the first analytical model proposed for the construction industry to assess the impact of integrating BIM on OSS. This technology should make BIM adoption easier in underdeveloped countries. This is an empirical contribution as it measures the hypothetical relationships between two concepts, namely BIM implementation and OSS.

6.2. Managerial Implications

The findings of this study hold significant managerial implications that can be employed by building experts to evaluate the effect of BIM adoption on OSS. These implications are outlined as follows:

- The provision of crucial activities that can be leveraged to improve BIM implementation makes this study invaluable to the AECO industries. Consequently, it enhances client satisfaction through superior visualization quality.
- The study's findings contribute significantly to decision-making processes concerning the evaluation of how BIM operations impact OSS.

6.3. Limitations and Future Recommendations

Despite its significant contribution, it is crucial to acknowledge certain limitations inherent in this study, which warrant careful consideration when shaping future research endeavors focused on examining the impact of BIM implementation on OSS.

Firstly, the geographical limitations of this study, which concentrated solely on Egypt, have implications for the generalizability of the findings. Consequently, the ability to draw broader conclusions becomes somewhat ambiguous. To address this limitation, future research should strive to expand the geographical scope by incorporating a diverse range of developing countries. This broader inclusion would enable researchers to gather a more comprehensive dataset, facilitating more robust inferences and enhancing the external validity of the study's findings.

Secondly, it is important to note that this study's questionnaire exclusively targeted building experts, potentially limiting the perspectives and insights obtained. To enhance the richness and depth of understanding, future research should consider widening the participant pool to include stakeholders from various disciplines and backgrounds. By incorporating a broader range of professionals, such as architects, engineers, contractors, and software developers, researchers can obtain a more holistic view of the impact of BIM implementation on OSS.

Finally, the omission of historical and organizational settings pertaining to the deployment of BIM represents another limitation in this cross-sectional research. To gain a more nuanced understanding of how BIM activities and OSS interact over time, future studies should adopt a longitudinal approach. By observing and analyzing the dynamic interplay between BIM and OSS within different historical and organizational contexts, researchers can uncover valuable insights into the long-term implications and effects of their relationship.

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