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Impact of Overcoming BIM Implementation Barriers on Sustainable Building Project Success: A PLS-SEM Approach

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Abstract: To maximize the benefits without sacrificing the functionality of projects, sustainability concepts should be used across all stages of the decision-making process when creating residential buildings. The primary sustainable aims may be improved with BIM activities. However, in the building sector of underdeveloped nations, BIM activities use informal methods. By examining the connection between overcoming BIM implementation challenges and the overall sustainable success (OSS) in building projects, this research seeks to establish a model for BIM implementation. Following the BIM hurdles identified in earlier research, 86 building stakeholders in the Egyptian building sector were given questionnaires. The structure of the obstacles was established and confirmed using partial least-squares structural equation modeling (PLS-SEM), and the connections between the OSS and overcoming BIM deployment were investigated. The adoption of BIM contributed 40.7% to the project's long-term sustainability, according to the data, which demonstrated a strong link. The findings of this research will serve as a roadmap for decision-makers who want to use BIM in developing nations' building sectors to save costs and increase sustainability.

Keywords: BIM; sustainable success; building projects; partial least square; structural equation modeling

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1. Introduction

Buildings are prerequisites for determining a country's residents' quality of life and health [1]. Systems for regulating temperature, power, ventilation, elevators, and water supply in buildings are called "building services" [2]. However, the demand for adequate housing exceeds availability in an expanding and more urbanistic environment [3]. Urbanization influences developed and developing nations because low-wage individuals have more challenges obtaining adequate accommodation [4]. For example, 828 million people below the poverty line live in slums and other low-cost dwellings in developing countries. By 2023, this number is anticipated to reach 1.4 billion. The projected increase in the world population from 3.6 to 6.3 billion people by 2050 indicates that more buildings would be needed to accommodate the rising demand for structures [5]. Consequently, cost-effective residential building regulations have been given top priority by national governments in several nations in order to achieve sustainable buildings [6]. In addition, a UN Environment Program (UNEP) assessment found that the building sector may significantly boost any country's economy. According to UNEP research, the building industry creates 5 to 10% of

all jobs nationwide and contributes between 5 and 15% to gross domestic product (GDP) [7]. Nevertheless, the building industry's actions have had adverse environmental effects. For instance, UNEP research reveals that building projects produce 40% of the world's energy and greenhouse emissions [8].

Furthermore, this sector produces a significant amount of waste and uses many natural resources [9]. Consequently, sustainable building is necessary for people to access eco-friendly buildings that use water, energy, and other resources wisely [10]. Another advantage of sustainable construction is lower operational expenses. Additionally, it raises productivity among residents and creates self-aware cities [11]. Overall, the information on sustainable buildings offers ways to deal with the ecological concerns. As a result, developing and industrialized nations strongly emphasize sustainable building [12]. Building activities have increased significantly in Egypt. The government is working to create a more sustainable strategy that will enhance the development of green buildings via the Egyptian Government Initiative [13]. The literature has emphasized the need of developing "sustainable buildings" that are resource-effective and ecologically benign [14]. Wolstenholme et al. [15] continue to fight for the building industry's modernization by including efficient and environmentally friendly procedures.

Furthermore, when structures are constructed, building experts are unable to quantify the environmental impacts of such projects [16]. As a result, throughout the planning and design stages of a project, Building Information Modeling (BIM) may be coupled to sustainability techniques [17]. BIM is at the forefront of technological breakthroughs, and there is a wealth of literature on this concept and its uses, which may be integrated with successful approaches throughout the planning and execution stages of a project [18]. Autodesk [19] defined BIM as follows: "a method that is based on intelligent 3D models that provide experts in building, architecture, and engineering are three distinct yet interrelated areas with the information and tools necessary to improve the efficiency with which we plan, design, construct, and manage our buildings, as well as our infrastructure". BIM has the potential to maximize productivity in building design, building, and maintenance [20].

BIM is still undergoing significant transformations in response to sector stakeholder demands for technology to solve the persistent systemic and recurring difficulties, such as those associated with productivity, cost, and time management [21]. The goal of BIM as a process is to use the most advanced technology possible to enhance production frequency and improve the return on investment (ROI) via simplified and uniform procedures [22]. In addition to existing projects, it allows the execution of a single hub of data that designers, engineers, mechanical, electrical, and plumbing (MEP) contractors, operators, and facility management (FM) businesses may use for various buildings of any kind and size [23]. As a result, BIM has been referred to as a vital lifecycle management tool that may significantly improve the lifetime of a building [24].

Although BIM is already a widespread technique for resolving building-related challenges in certain industrialized countries, most developing countries, including Egypt, have not yet given it the same attention. However, developing nations like Egypt are gradually using BIM, despite the shortage of study on the difficulties to BIM adoption in Egyptian residential building projects. This promotes ad hoc techniques that do not save building costs, such as poor collaboration. Because sustainable environmental regulations and other standards and procedures have suffered from stagnation since the year 2011, the BIM standard must be implemented in Egypt's building sector [25]. As a result, BIM must be used in Egyptian residential building projects.

We formulated the following research question for this empirical investigation in light of our arguments. What effects would the elimination of implementation obstacles for BIM have on the OSS in residential building projects? Through the use of the partial least square (PLS) modeling technique, the current study sets out to fill this gap by statistically examining the link between overcoming the implementation challenges for BIM and the overall sustainable success (OSS). This study examines the relationship between removing the application barriers in BIM and sustainable building from the viewpoint of user

application behavior. It also aims to identify the significant driving forces behind BIM application behavior to increase the effectiveness of BIM's use in sustainable building. The current work explicitly develops a theoretical model by fusing the planned behavior theory with BIM implementation. As a result, embracing BIM will help decision-makers to complete their building projects successfully by reducing unnecessary costs and improving the quality of the buildings. The Egyptian building sector, where there is a lack of awareness of the value of BIM, should benefit from this study. The remaining portion of this paper discusses the current level of knowledge in this area, followed by the chosen research methodology. Then, the proposed PLS-SEM model and findings of this paper are discussed in light of the previous literature. Key findings and future recommendations are presented in the conclusion.

2. Research Model Development

2.1. Obstacles to BIM in Building Industry

Aranda-Mena et al. [26] highlighted one of the key challenges to using BIM as the issues with interoperability across the various BIM applications. According to Ku and Taiebat [27], different software packages cannot communicate straightforwardly; hence, the data captured in a specific software package must be processed once again on the software, rather than being tied to one another. Reaching this point is the primary objective of utilizing BIM. The exchanges mentioned above are referred to as interoperability. Interoperability is essential to the success of BIM, since a project is comprised of several interactions between the different parties involved throughout the building project's life cycle [28]. According to recent studies, the BIM software support solutions of SMEs are only partially effective [29]. Because of the one-of-a-kind data structure inherent to BIM models, there have been problems over the ownership of the multiple pieces of information about design, manufacture, analysis, and building [30]. The investigation of the obstacles that stand in the way of BIM is one of the issues; one problem that emerges is the degree of responsibility for the precision that is required of each expert, as well as the question of who is to be held liable for design inaccuracy [26]. In the traditional, paper-based design method, the architect, in addition to engineers and other specialists, may be held responsible for his/her designs, but in the BIM program, accountability cannot be readily identified [31].

Preceding revisions, including those by Chan [32], argued that a lack of competent employees makes adopting BIM more difficult. In addition, Aranda-Mena et al. [26] was noted that in locations where there are no employees who can encourage the adoption of BIM, there is no difficulty talking about it because there are no individuals who can carry it out in those locations. Consequently, adopting BIM is an illusion in a location with a shortage of professionals with the requisite skills and training. However, Sebastian [33] states that utilizing BIM for projects that do not have appropriately coordinated and planned contract procedures are generally considered to be complex. This is because the contractual method is not adequately prepared to integrate such advanced technology. In addition, it was determined that resolving the issue of people's roadblocks to contractual coordination is necessary to successfully apply BIM in a project that involves a substantial amount of cooperation. BIM cannot be accepted since its implementation must be included in the contract from the beginning, and if the processes are not adequately stated, BIM cannot be implemented [34]. Because modifications need to be made before BIM can be implemented effectively, some companies have chosen to avoid it. Using a centralized building model during the design phase and a synchronized collection of building models throughout the building and production phases are two of the most fundamental adjustments that must be made when a company adopts the BIM concept [27].

However, some industry experts still do not view BIM as a competitive alternative to traditional building techniques. This is because such individuals do not acknowledge the disadvantages of traditional building methods [35]. As is the case with most other developing nations in Sub-Saharan Africa, Nigeria has no government legislation focused on expanding BIM usage and comprehension. This constraint starkly contrasts the options that

are accessible in industrialized countries such as the United States of America, the United Kingdom, and China [27,36]. The lack of a group similar to this inside the government has discouraged other private sectors from adopting BIM implementation efforts seriously. This is because the government continues to be the dominant owner of projects. Since this is the case, it is expected that they will lead the way for additional stakeholders to follow [36]. Similarly, the absence of activities and study areas on the part of the government is an obstacle to adopting BIM in Saudi Arabia [37]. Accordingly, the challenges that Saudi Arabian building companies experienced were a lack of participation from customers and stakeholders, limited competence from BIM groups, and a lack of mentorship from a BIM advocate [38]. The issue of who is responsible for the design, who may make ownership claims, who is entitled to patent rights, who should build and administer BIM, and how the expense of adoption should be split or divided, among other things, are all aspects of the difficulties associated with BIM adoption or usage [39]. Likewise, Gamil and Rahman [40] also suggested that the key hurdles for BIM are budgetary limits, a lack of awareness of BIM, inadequate understanding of BIM methodologies, a lack of awareness and advantages of BIM, and a lack of assistance from the government. Several elements operate as deterrents, some of which are dependent on the geographic location, the economic situation of the country, government policy, and willingness to change and are often a problem for the implementation of BIM. Several of these challenges, which a wide range of academics has noted, have been compiled and are shown in Table 1.

Table 1. BIM adoption obstacles.

Variables	Code
Technology and business	
The availability of software	B6
Poor coordination and management of contractual responsibilities	B12
Information and proprietary intellectual property	B2
Availability of the technology	B4
Training and people	
Lack of knowledge and experience	B9
Concerns about interoperability	B1
The resistance shown by other interested parties	B10
Cost and standards	
The expense associated with the exchange of data and information	B8
Alterations both in business and culture	B7
A lack of norms that have been stated	B5
Process and economics	
The cost of implementing BIM	B3
Inadequate research on BIM and a lack of relevant information	B14
Inadequate policies and procedures from the government	B11
Lack of demand for the deployment of BIM	B13

Note: Adapted from [31].

2.2. Overall Sustainable Success

Countless research has emphasized the topics related to environmental preservation [41]. The process of transforming projects' sustainability management aims and plans into operational procedures is complex [42]. Maintaining a healthy equilibrium between social and economic sustainability and environmental considerations is crucial [41]. The proliferation of environmentally conscious building practices has prompted the building sector to look for real-world sustainability applications in the current office setting [43]. Drivers that might boost the extensive adoption of BIM throughout the key strategic stages include the need for sustainable improvement and the creative corporate social responsibility ethic applied by corporations [44]. Regarding environmentally friendly building practices, BIM's contribution to the building procedures may be compared to the three significant components of sustainability, including sustaining the environment, the economy, and society.

2.2.1. Economic Variables

One of the most significant contributions to sustainable building comes directly from BIM through the cost estimating and risk management process. It is one of the many goals that BIM was designed to accomplish [45]. The process of estimating the expenses of the project and the resources that will be needed may be broken down into many steps in order to estimate and quantify the costs associated with each phase [46]. In contrast, project managers may incorporate time into their analysis and use 4D models to more effectively and efficiently analyse the risks associated with the project in order to reduce project costs in addition to the 3D models of BIM representations [47]. This strategy may make a project more progressive and cost-effective, but it is not sustainable unless it factors in the environmental advantages, enhances the quality of life, and prioritizes human well-being and societal values [48]. In addition, the application of BIM to other facets of the project may play a significant part in the overall economic efficiency of the endeavor. For example, by forecasting the future and improving collaboration and communication among the stakeholders, wastage can be decreased, time can be saved, building management may be improved, and the project's overall cost can be reduced [45].

2.2.2. Environmental Variables

As the design evolves, BIM collects a large portion of the data required for performance analysis. Using a building information model, designers may quickly evaluate the design possibilities to achieve a greener design. BIM may predict a building's performance after building [49]. The vast majority of BIM tools contain a variety of functions for analyzing energy and material consumption analyses, as well as the electrical and mechanical section of the building, so that it can provide specific information on reducing the amount of energy and materials wasted [50]. Some of the BIM software, such as Autodesk Ecotect and Revit, gives users access to a shared set of tools that process information and analyze the environmental aspects of a project. This makes it much easier for architects and designers to control energy and use resources effectively. This kind of software may integrate data to provide a more environmentally friendly design by analyzing the solar path, building orientation, shading design, and estimating heating and cooling needs [50,51].

2.2.3. Social Variables

According to the Western Australia Council of Social Services (WACOSS), social sustainability is defined as the circumstance in which formal and informal processes, systems, structures, and relationships actively support the capability of current and future generations to create healthy and liveable communities. This is how social sustainability is achieved. A high quality of life is provided with social equity, diversity, connectivity, and democratic governance in socially sustainable communities [52]. In most cases, the advantages of sustainability for social elements are addressed within the context of the improvements made to other areas of sustainability, which ultimately leads to the promotion of human well-being, comfort, and health [48]. Regarding sustainability, the social principle addresses a wide range of concepts and definitions, all of which can be broken down into the following two distinct categories regarding their relationship with BIM: dependent characteristics and independent features. In addition, these concepts and definitions can be broken down further into specific subcategories within each category. The dependent features of social sustainability are more quantitative and can be directly measured through a variety of other assessments that BIM can provide for a wide range of aspects of the environmental condition. These assessments include energy performance and lighting. These are the kinds of features that contribute to the social sustainability of an organization.

According to Sassi [48], negative conditions can encourage health issues such as stress, discomfort, and absenteeism, but positive conditions can improve some environmental elements through sustainable design, which induces health and performance-boosting effects. Therefore, the total impact of these kinds of considerations is beneficial to the entire community and society. On a societal scale, sustainable design can improve one's

quality of life in several additional ways, the most common of which are the transfer of knowledge, the improvement of environmental quality, the restoration of neighborhoods, and the reduction in health risks from the pollutants associated with the use of building energy [28].

Lin and Hsu [53] used a web-based application programming interface (API) to employ BIM to assist in problem envisioning and management. This example exemplifies the ability of BIM to identify difficulties and task progress early on. Raouf et al. [54] suggested that BIM has transformed typical engineering project management practices that impact the project lifecycle. BIM is utilized in a variety of ways during its lifespan, which is frequently broken up by participation from a wide variety of professions over the various phases of development, which will be abbreviated as design, building, and operation (e.g., designers), building (e.g., contractors), and operating stages (e.g., facility managers) [55,56]. As a consequence of this, based on our reasoning presented earlier in this study and displayed in Figure 1, this study made the following hypotheses (H1):

H1. *There is a significant relationship between overcoming BIM implementation and the OSS.*

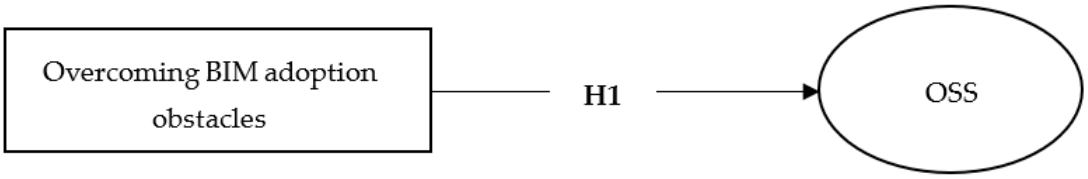


Figure 1. Influence of BIM implementation barriers on the adoption of OSS.

3. Research Approach

This research aimed to analyze and identify the challenges that are preventing companies in the Egyptian building sector from using BIM. Consequently, a critical literature review methodology was implemented throughout the exploratory research, and several phases of data gathering and organization were utilized following this [57]. A critical review goes beyond the simple presentation of well-known articles to integrate some insight and conceptual creativity; it demonstrates that the author has methodically analyzed the prior research and substantially appraised the data [58]. Data for this study were acquired by considering a wide variety of materials, such as published publications, research papers, government documents, and green building codes. This method was used to acquire comprehensive information and knowledge. After this, the study of the data and the refining and categorizing of the earlier investigations were carried out. During the data review process, the quantity of information that was obtained was cut down through the processes of selection, simplification, and data abstraction. The preceding discussion deals with organizing the data into essential categories and structures [59]. This categorization was accomplished by ensuring that each piece of information was assigned to the relevant subgroups (subconstructs), which were then assigned to primary constructs [57].

Through a process of continuous review that includes data gathering, refinement, and categorization, this methodology assists the writers in interpreting raw data and formulating hypotheses. After this, the PLS-SEM was developed through an exhaustive review procedure to formulate hypotheses that could later be tested using empirical evidence [60]. The development of the conceptual model that will be used in this investigation is broken down into the following three primary stages:

(1) The identification of model constructs;
(2) The classification of model constructs;
(3) The investigation of the link between constructs.

Figure 2 demonstrates that the first step was completed by reviewing the current literature (BIM barriers and OSS). Subsequently, the classification of BIM barriers was carried out after this based on the categorization performed by Olanrewaju et al. [31]. The final step consisted of structural equation modeling (SEM) analysis to investigate the

connection between a dependent construct (BIM barriers) and an independent construct (OSS). This brought the process to a successful conclusion (Figure 2).

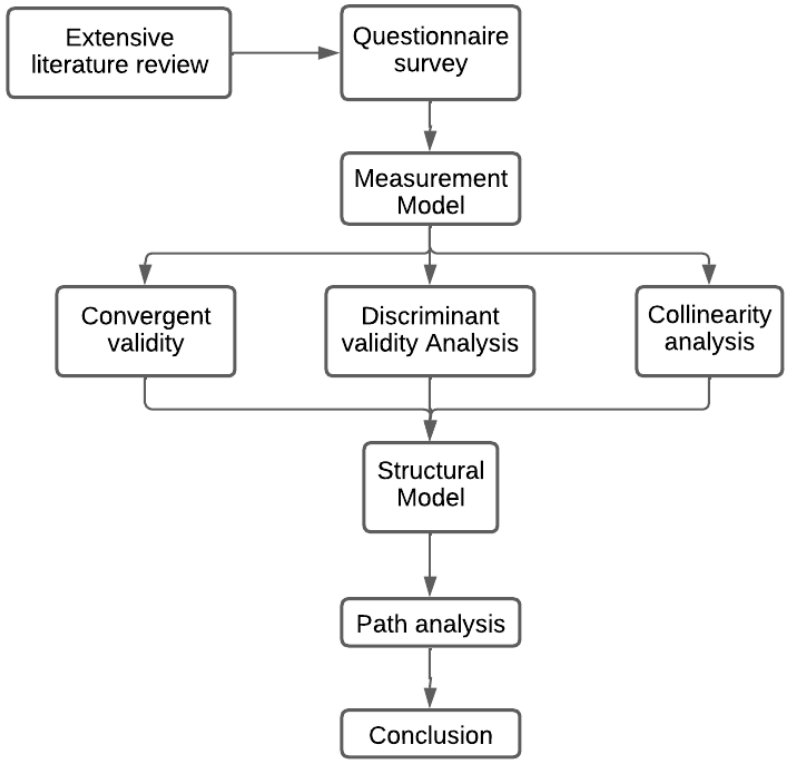


Figure 2. Research design.

Analytical Approach (Structured Equation Modeling)

The SEM methodology was utilized to investigate how successfully overcoming BIM hurdles impacted the OSS. The SEM approach draws attention to the relationship between many observable factors and non-observable variables [61]. SEM is an effective method for addressing issues about variables and mistakes [62]. This study used the SEM technique to evaluate the association between overcoming the BIM hurdles and OSS. The relationship between the specified indicators and each construct was observed while the investigation was carried out [63]. It is a process that takes the form of equations and includes both random variables and structural bounds [64]. SEM has only recently, according to Byrne [65], been identified as a non-experimental study method when proper techniques for hypothesis analysis are not used.

SEM has only recently, according to Byrne [65], been identified as a non-experimental study method when proper techniques for hypothesis analysis are not used.

Similarly, Ringle et al. [66] showed that the use of this technique has increased over the years and is often included in studies published in *MIS Quarterly*. It is also a widely used instrument in social science data [67]. In order to determine the nature of the connection between overcoming BIM hurdles and the OSS, the partial least square (PLS) model was established. This model takes into account both reflective and formative aspects. Despite this, the PLS-SEM analysis was performed on the data from this study using three different significant evaluations (standard method variance, measurement model, and structural model) [68]. PLS-SEM is commonly used as a route model because it establishes relationships between independent and dependent components [69].

4. Results

4.1. Common Method Bias

A computation of variance that affects the validity of the analysis and aims to highlight the error variance associated with the measured variables is referred to as common method bias [68]. To determine traditional method variance, a single-factor analysis was carried out on the suggested model [70]. It has been proven that typical technique bias will not affect the data gathered if the overall variance of the variables is less than 50% [71]. The results of this study demonstrate that the first group of components accounts for 33.43% of the overall variance; hence, the standard method variance is not capable of influencing the outcome because it is lower than 50% [71].

4.2. Measurement Model

The measuring model demonstrated the link between the items and the latent construct that lies behind them [72]. In PLS-SEM, assessing the reflective measurement items (BIM barriers and OSS) entails analyzing the instruments' convergent and discriminant validity [73].

The concept of convergent validity refers to the degree of coherence and arrangement within two or more barriers of the same construct [74]. The convergent validity of a construct is evaluated using the construct validity sector. The following set of tests may be used in PLS-SEM to provide an estimate of the convergent validity of the suggested constructs [75]: composite reliability scores (ρ_c), Cronbach's alpha (α), and average variance extracted (AVE).

As shown in Table 2, Cronbach's alpha also reached a value of 0.60. Nevertheless, according to Table 3, all of the BIM barriers and OSS constructs achieved composite reliability values of more than 0.60 and were consequently accepted [76]. Nevertheless, as shown in Table 2, Cronbach's alpha also reached a value of 0.60. According to Perry et al. [77], recommendations indicate the dependability ranging from moderate to high. Additionally, the AVE was utilized to assess the converging validity of the construct variables. An AVE value that is more than 0.5 is considered to be appropriate. Fornell and Larcker [75] suggest that the measurement variables absorb at least 50% of the variance [78]. According to Table 2, taken from the PLS 3.0 program, the estimations of AVE values obtained from this study are more than 50% for each of the components. Based on these findings, it is clear that the measurement model is internally consistent and convergent. In addition, it suggested that the measurement components for each construct are accurate and do not quantify any of the other constructs included in the study model. However, according to Hulland [74], the value of the external load with a coefficient of 0.70 is preferable; however, if the analysis performed is explanatory, the value of the external load with a coefficient of 0.40 or higher is considered as suitable [17,61,79–81]. The outside loads for each measurement in the PLS model are displayed in Table 2 and Figure 3, respectively. As a result, all outside loads are acceptable [79], except for B3, B7, and B14.

Table 2. Reliability results.

Constructs	Cronbach's Alpha	Composite Reliability	AVE
Technology and business	0.71	0.772	0.534
Training and people	0.72	0.751	0.506
Cost and standard	0.73	0.773	0.630
Process and economics	0.721	0.808	0.678
OSS	0.710	0.838	0.633

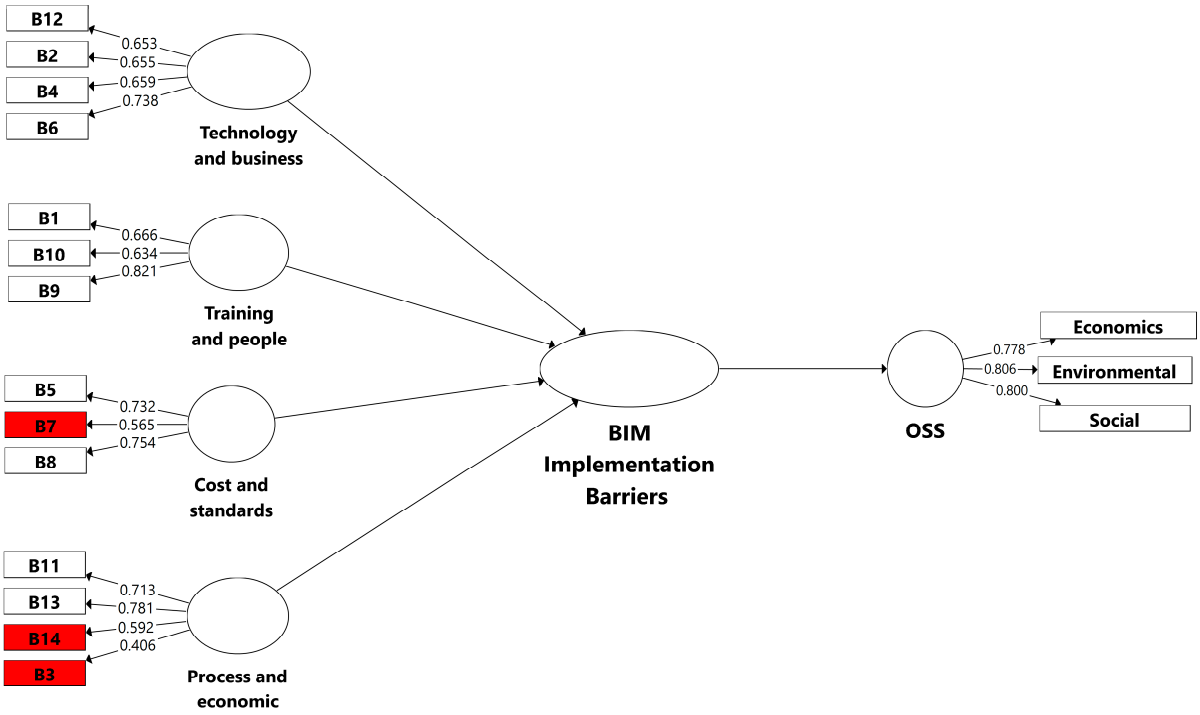


Figure 3. The PLS model.

Within the SEM study, the evaluation of discriminative validity has become an increasingly essential and well-liked approach [82]. Its purpose is to establish whether or not the construct under investigation can be empirically distinguished from others [83]. Within the scope of this study, discriminant validity was evaluated using the following approach:

(1) Fornell–Larcker criteria

According to Fornell and Larcker, the observations in Table 3 indicate that the discriminative validity of the BIM barriers and OSS constructs are acknowledged and approved. This is because the square root of the AVE needs to be higher than the correlation between the construct indicators and variables for this to be the case [84].

Table 3. Fornell–Larcker analysis.

Constructs	Cost and Standards	OSS	Process and Economics	Technology and Business	Training and People
Cost and standards	**0.794**				
OSS	0.24	**0.795**			
Process and economics	0.337	0.511	**0.824**		
Technology and business	0.562	0.232	0.349	**0.677**	
Training and people	0.516	0.422	0.534	0.482	**0.711**

4.3. Second-Order Analysis

Strong relationships between the measurements of the formative measurement models were unexpected because the constructs for the BIM hurdles utilised in this investigation were formative. Correspondingly, the vital link among the formative factors indicates the existence of collinearity, which reflects a problematic situation [85]. Consequently, this study looked at the variable inflation factor (VIF) value to observe the collinearity among the formative elements of the construct. Since this study focuses on the reflective and formative kinds of first-order constructs, the findings demonstrate that all the VIF values were less than 3.5, indicating that each construct contributed to BIM obstacles separately. However, as indicated in Table 4, four first-order subscales for the BIM obstacles had a

significant route coefficient (outer weight). These subscales were "Cost and standard", "Technology and business", "Process and economics" and "Training and people".

Table 4. Formative construct analysis.

Paths	B	*p* Values
Cost and standards -> BIM adoption barriers	0.242	0
Process and economics -> BIM adoption barriers	0.306	0
Technology and business -> BIM adoption barriers	0.383	0
Training and people -> BIM adoption barriers	0.356	0

4.4. Structural Model Analysis

The reliability and statistical significance of the data set selection, as well as the observed path coefficient (*p*-value and outer weight at the 95% confidence interval (CI0.95), respectively), were put to the test using this method [86]. In addition, the essential part of the analysis was to determine whether or not the proposed study hypothesis was correct. The importance of the model hypothesis was examined using the structure and essence of the bootstrapping method [87]. A bootstrapping method was utilized to produce fresh samples of the same size as the original data set. This was accomplished by randomly resampling the original data set [79]. It helps to determine the accuracy of the data set and, consequently, the inaccuracy of the measured path coefficients [88]. In addition, the following statement has also been made: "*The value between each route is the path coefficient, which measures the influence of one construct on another*" [89]. In light of this evidence, the hypothesis of a causal link between GBP (the overcoming BIM obstacles concept) and the OSS was formed. Therefore, in this circumstance, the structural link among the GBP, and EUR 1 equation in the structural model, which was recognized as the inner relationship, may be expressed as a linear equation as follows [90]:

$$\mu = \beta\ £ + €1 \quad (1)$$

By overcoming the BIM obstacles created at this structural level, residual variance is projected to exist in (EUR 1), where (β) is the route coefficient that links the two. Consequently, the weight of standardized regression analysis corresponds precisely to the weight of multiple regression analysis. The sign of the variable must be statistically significant and coincide with the prediction made by the model. However, it is challenging to ascertain the importance of the route coefficient, as denoted by Kineber et al. [80]. Regarding canonical factor analysis, a method called bootstrapping, part of the SmartPLS3.2.7 software, was utilized to calculate the errors of the route coefficient. Henseler et al. [91] extended this to 5000 different samples in light of this and developed the t-statistics for proposition testing. For the PLS model, one structural equation was constructed to overcome the BIM barrier construct. This equation was used to characterize the inner relations among the constructs and Equation (1). Therefore, the standardized (β) and *p*-values, in addition to the significance of the route, were assessed with the endogenous construct in mind (Table 5). Table 5 and Figure 4 explain the results obtained from the bootstrapping analysis. According to these findings, the impact of "overcoming BIM hurdles" and "OSS" was beneficial and statistically significant ($p = 0.0005$; (β) = 0.426). As a result, the two most important aspects of this study—overcoming the hurdles of BIM and OSS—head in the same direction (i.e., overcoming the BIM barriers as the OSS increases).

Table 5. Path model analysis.

Paths	B	*p* Values
BIM adoption Barriers -> OSS	0.426	0

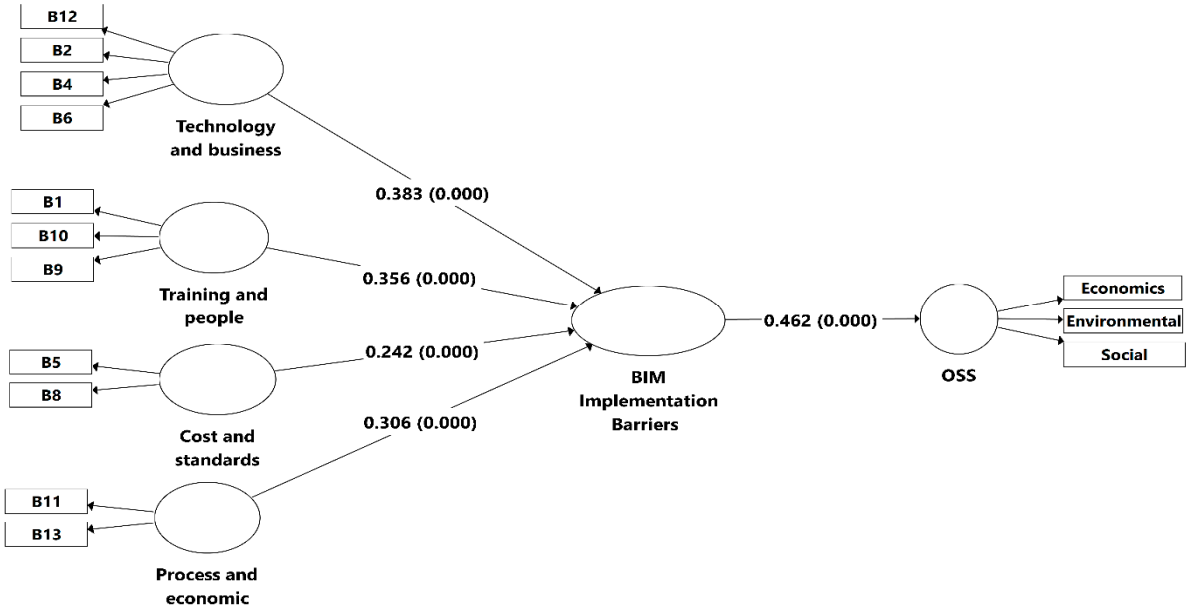


Figure 4. Bootstrapping analysis.

4.5. The Structural Model's Explanatory Power (R^2)

One of the most essential evaluations in PLS-SEM is determining the R^2 value for the endogenous variables. The findings demonstrated that the R^2 and modified R^2 values for OSS in this study were 0.207. This indicates that the exogenous latent variable (BIM barriers) may be able to account for 20.7% of the OSS. These results demonstrated that the size set by the BIM barriers is sufficient and may be characterized as having a somewhat small impact size [61].

4.6. IPMA

The PLS-SEM methodology points to the importance of an independent construct in explaining the model's dependent construct [73]. The outputs of the PLS-SEM were expanded with the help of the importance performance matrix analysis (IPMA), which also reflects the variable performance. The following should also be noted: "*The IPMA study findings might be shown from two perspectives (importance and performance), both of which are critical for management is a systematic process*" [73]. The overall implications of the structural model's importance and the average value of the construct variable levels' performance were considered to focus on crucial and significant aspects that contribute to improving management activities. Within the scope of this study, the IPMA serves as a dependent construct for the BIM barriers. The proposed model displays the exogenous variable's (BIM barriers) degree of relevance and performance with "OSS" as the target variable; it was discovered that all of the variables had high relative importance (0.477) and performance with "OSS" as the target variable (65.8).

5. Discussion

5.1. Understanding the Role That Overcoming BIM's Limitations Has in OSS Development and Deployment

PLS-SEM is used to explore the relationship among the constructs (overcoming BIM barriers BIM and OSS). According to the findings of our study, eliminating 40.7% of the obstacles posed by BIM contributes to an improvement in the OSS. Conquering the obstacles presented by BIM has a crucial relationship with the OSS. Nevertheless, the findings suggested that the value of 0.638 should be utilized whenever the organization successfully overcame 1 unit of BIM hurdles. In addition, this will also result in a 40% rise in the OSS. According to Ghaffarianhoseini et al. [92], BIM has also been regarded as a decision-support technique that supports designers in analyzing the quality of various

designs in terms of energy, emissions, and price. This is because BIM allows designers to compare the performance of various designs more easily. According to Ibem et al. [93], it makes it easier to effectively visualize the customer's design for approval purposes. BIM is not a panacea for all of the problems that plague the building sector. It is gradually being integrated into the more comprehensive concept of Industry 4.0, which stands for a higher convergence of digital technology [94]. In order to persuade the building stakeholders to comprehend how BIM may be implemented, overcoming the constraints that prevent the deployment of BIM is necessary.

According to Sidani et al. [95], there is still a need for prominent industry participants to learn how to manage BIM approaches, which identifies opportunities for more significant growth in accessing, managing, and transferring BIM data. Additionally, a suite of sophisticated project management tools that enable greater insight and understanding of complex modern projects has been combined to deliver a suite of the Internet of Things, artificial intelligence, big data analytics, sensor-based technologies, and other technologies [96].

5.2. Determining the Extent to Which OSS May Be Improved by Removing the Obstacles Presented by BIM

According to the findings, the social obstacles ranked first with a score of 0.638 for the path coefficient. According to the findings, societal success will increase once these challenges associated with implementing BIM have been conquered. The environmental category is responsible for the second element, which has a path coefficient score of 0.924. The findings determined that improving the project's environmental impact might be one aspect of overcoming the obstacles connected to BIM. The economic variable is the variable that is ranked last, with a path coefficient score of 0.858. This study's conclusions are consistent with those reported by Biancardo et al. [97]. They stated that the implementation of BIM has considerably helped to reduce the costs and time associated with building, particularly throughout the building process. In a similar vein, the participants were required to consider how the utilization of BIM in building companies helps to mitigate risks. This will illustrate the significantly high costs associated with investing in and enhancing building environments [98].

5.3. Major Obstacles to the Deployment of BIM

The first hurdle that BIM must overcome pertains to both technology and business. This component includes conditions that relate to "software accessibility, poor contractual administration and coordination, data and intellectual property, and technological availability". According to the PLS-SEM model, which has a path coefficient of 0.635, this component dramatically influences the difficulties associated with BIM implementation. For the exercise to be successful, it is essential that both technology and business embrace and accept BIM adoption. This finding concurred with that reported by Ugliotti [99]. The adoption of BIM, he claimed, faces several challenges throughout the operation and maintenance phase, including insufficient organizational and legal problems that obstruct BIM implementation and the inadequacy of technology, procedures, people, and processes all play a role. According to Vass and Gustavsson [100], the business sector has been transformed due to growing digitalization, eliminating potential drawbacks and making traditional methods progressively obsolete. Hoang et al. [101] emphasized that the primary barriers to the implementation of BIM in infrastructure projects include "a lack of connectivity between BIM and present technologies", as well as "how applicable knowledge in BIM models may be merged with existing facility management information systems and software resources".

Furthermore, Saka and Chan [102] observed that the majority of a country's BIM adoption barriers are people and process-related, followed by technology barriers. As a result, the BIM process has to be integrated with regular business activities [103]. Increasing the number of businesses that use BIM will need active support from the government, in addition to developing a new communication strategy [17].

Businesses that use BIM usually struggle with the high and escalating costs of buying BIM software, upgrading hardware, and planning for BIM adoption [104]. The second main factor is associated with the "expense and standards" variable. Barriers include the "cost of exchanging data and information, corporate and cultural shifts, and absence of set standards". With a route coefficient of 0.411, the "cost and standard" influence on the BIM obstacles is moderate. These results concurred with those reported by Mahdi et al. [105]. They assessed and examined the most significant barriers to BIM adoption in Iraq's building sector. Their research shows that the primary barriers to implementing BIM in the Iraqi building sector may be influenced by social and cultural issues due to the lack of BIM-related investments, a lack of experience, the absence of a national BIM standard, and the resistance to change.

It is also required to formalize and construct BIM sub-models more rapidly to offer more excellent coverage of user needs and information flows over the whole lifecycle of architectural engineering and construction (AEC) projects. BIM sub-models can only be created if they are formalized. In Yemen, there is a lack of BIM competency, financial restraints, and evidence of the wrong introduction of BIM principles and standards, and both factors together, according to Gamil and Rahman [106], are the most critical barriers to BIM adoption. Similarly, Alhumayn et al. [107] investigated the obstacles and methods for BIM implementation in Saudi Arabia. According to the findings, the largest barriers to BIM adoption are a lack of management support for adopting changes in the current practices, a lack of practice standards and guidelines, and a lack of attention from policy-makers and the government. In addition, Reza Hosseini et al. [108] considered that a significant obstacle to adopting BIM might be the absence of data that demonstrate the financial benefits to organizations, particularly small and medium-sized enterprises (SMEs). Therefore, for BIM to be adopted in underdeveloped countries, there must be demand from clients and vendors, in addition to government support [109].

The "Training and people" variable is the third main component. This element covers the circumstances and setting in which people operate to foster fruitful interactions and cooperative working relationships between professionals and stakeholders. Barriers to this concept include a lack of expertise and training, problems with interoperability, and resistance from other parties. With an external value of 0.390, "Training and people" is third on the list of obstacles that prevent the adoption of BIM. This finding is in line with that reported by Arrotéia et al. [110]. The client's lack of interest in adopting BIM-developed projects, owing to the increased time and expense of the projects, as well as a lack of knowledge and skills and confusion about how BIM is utilized in the design process and how it connects to the building were the main obstacles to Brazil's adoption of BIM.

The potential obstacles to the deployment of BIM are highlighted by Hatem et al. [111]. According to their findings, "poor government attempts to apply BIM" are the most significant potential barrier to BIM adoption. The "lack of BIM experts" was considered as a possible BIM hurdle. The lack of BIM expertise and training is the third potential BIM barrier. Furthermore, in Canada, Moazzami et al. [112] concluded that conflict detection, constructability, and job sequencing are the crucial functionalities that may be improved by BIM deployment, based on the BIM experience of members of the architecture engineering community. Inadequate stakeholder management, lack of user understanding, and resistance to cultural change are other problems that result in poorer BIM implementation [113]. A project team should have BIM knowledge, including collaboration, experience, and prior BIM technological knowledge [114]. Collaboration between disciplines is essential for implementing BIM [22]. However, related knowledge is required for the effective adoption of BIM. Succar [115] argued that BIM is acknowledged as a broad field of expertise in the building industry that is constantly expanding. Design intent and expertise must be communicated and included in BIM [116]. As a result, BIM research and development are necessary to motivate building professionals to study and improve their knowledge. It has been asserted that a lack of research and development also hinders the use of BIM data [117]. According to Khosrowshahi and Arayici [118], education and research are

crucial factors in adopting BIM, due to the technical and operational developments in firms today. Additionally, creating a BIM task group to evaluate the market's potential might raise awareness of BIM programs and needs [119]. Additionally, building stakeholders should encourage their personnel to enroll in BIM training programs to remain aware of the abilities that need to be developed to acquire real-world knowledge and practical skills [120].

The final major factor that affects BIM hurdles is "Process and economics". It includes roadblocks such as the price of adopting BIM, the absence of demand for BIM implementation, and insufficient guidelines and plans from the government. With an external coefficient of 310, the "Process and economics" impact on BIM obstacles appears to be identical to that of "Training and people". This finding suggests that the adoption of BIM is often successful when process and financial constraints are avoided. This outcome is also consistent with the recommendation made by Hoang et al. [101]. They contend that the primary BIM hurdles are organized process strategies, uses, and information. These findings are also consistent with those reported by Umar [121] for the Gulf Cooperation Council (GCC) area, who studied the present state of BIM in the GCC building sector and the obstacles involved with BIM adoption. The research indicates that organizational, technological, governmental, and legal challenges are the key challenges present in this area.

Nevertheless, Tuckwood [122] stated that establishing legality is time-consuming, but mandating BIM is a better way to execute it. A further issue that slows the adoption rates is industry opposition to change and a dearth of knowledgeable and skilled BIM practitioners and instructors [101]. As a result, business professionals and academic institutions must work together to develop a BIM implementation program that aligns with business procedures [48]. Governments should support BIM applications through different laws and initiatives, since they stand to gain the most from its adoption [32]. The government may help to assess the industry's readiness for BIM and invite BIM specialists to assist the sector in developing its BIM adoption plan [92].

The previous discussion makes it abundantly clear that BIM barriers impede the development and application of the BIM technique. This has resulted in considerable losses for several engineering projects. In addition, most of the prior research examines the obstacles that stand in the way of BIM by conducting a literature review and a questionnaire survey. There is a dearth of research on the connections and effects between various barriers, whereas current research concentrates on identifying the existing barriers. Unlike other studies, this study examines the barriers to BIM from a new perspective and uses strong research techniques. The first step in identifying the obstacles to BIM adoption in the current building industry is to conduct a literature review. Second, a thorough study of the linkages between barrier components was conducted as the conceptual framework was created, following the investigation of the barriers to adopting BIM. In order to regulate and remove BIM impediments from the model's perspective, SEM is used to analyze the significant challenges. Dong [123], however, has examined the implementation hurdles and suggestions for BIM regarding project cost by utilizing the decision-making test and evaluation laboratory method (DEMATEL). We have concluded that the promotion of senior management has become the primary driver of the growth of BIM, and the lack of policy support from both the government and industrial businesses has the most significant impact on the other variables.

The application of BIM in the United States was investigated by Fountain and Langar [124], who found a variety of barriers to its full adoption. An in-depth study on BIM outsourcing revealed that the respondents believed that internal BIM implementation is more efficient than outsourcing. In a study of the UK building sector, in order to reduce obstacles to BIM implementation, Piroozfar et al. [39] found that integrated project delivery (IPD) can enhance the early engagement of essential parties, improve participation barriers, and address the assumptions about the degree of trust amongst several key stakeholders. Charef et al. [125] investigated the gaps in BIM application obstacles in 28 EU nations and discovered a significant disparity in BIM application levels among EU countries, which

might stymie cross-border initiatives and collaboration. Egypt's building industry is transitioning from CAD to BIM. At the same time, these businesses must contend with the issue of employing building energy models (BEM) to fulfill energy-saving goals. Khodeir and Nessim [117] investigated the present status of BIM2BEM application in the Egyptian building sector and the associated application obstacles. Scholars from New Zealand [126], Sweden [127], and other nations have also looked into the barriers to BIM implementation in their own countries.

Many researchers have looked at the difficulties in implementing BIM in China, a nation that vigorously promotes the use of BIM. Liu et al. [128] conducted an exploratory study on the obstacles to BIM adoption in the Chinese building industry, using this knowledge and the current research environment in that sector. Several factors are impeding the development of BIM in China, including "the lack of comprehensive evaluations on BIM's use value, the lack of BIM professional software and government promotion, the imbalance in the business levels of building enterprises, the difficulty of designers' conversion thinking, and the lack of relevant standards". Through the use of a game concept between government and business, Boya et al. [129] concluded that the government's economic strategy hinders BIM from being popular in China. Through a questionnaire study of building industry personnel, Liu and Zhao [130] discovered 15 reasons for the limited growth of BIM in China. In Sun and Wang's study [131], information asymmetry theory and game theory were used to investigate BIM development and the game of project owners and contractors. They concluded that the conflict of interest between project owners and contractors is a fundamental issue that is hindering BIM's growth. Li et al. [88] examined the slow promotion of BIM in China using a literature review, interviews, and a questionnaire from the owner, designer, and contractor perspectives. According to the report, the owners' lack of BIM understanding, designers' emphasis on unclear return on technology investment, and contractors' concern about changing working modes are the largest impediments to BIM promotion.

The following six challenges have impeded China's BIM implementation: a lack of government leadership, organizational problems, legal issues, a high application cost, a struggle to modify the population's thinking style, and a lack of external incentives. Zhou et al. [104], by using factor analysis and a structural equation model, and Zhang et al. [132] showed that the primary implementation challenges to BIM technology in sustainability projects are public engagement, technological acceptance, economic cost, and application administration, with public participation being an essential factor. In addition, utilizing principal component analysis, Ozorhon and Karahan [133] investigated the factors that influence the implementation of BIM in developing countries, where BIM is still relatively new to the building sector. According to the results of this research, the three factors that are the most important are as follows: (1) competent personnel; (2) good leadership; and (3) knowledge and technology that is readily available. In addition, the same technique, known as principal component analysis, has been used by Ma et al. [134] to research the obstacles that stand in the way of BIM implementation in the AEC project and to look into the causes of such obstacles in the Chinese project. According to the main component analysis, all of the obstacles were comprised of six underlying factors. These variables were expertise and capabilities, technical conditions, system inertia, extra input, change in work routines, and adoption risks.

5.4. Contributions to Theory and Research

The created model stresses the significance of removing obstacles to BIM deployment, particularly in developing nations with significant uncertainty. The model emphasizes the critical obstacles to the adoption of BIM. Policy-makers and other government institutions may use these hurdles to develop an action plan that will increase the adoption of BIM in the architecture engineering, construction, and operations (AECO) industry. Additionally, there is a distinct lack of research that looks at how the OSS and BIM obstacles interact in the Egyptian building industry. The study began by assessing all the key obstacles to

BIM adoption in the building industry. This study creates a robust platform for future research on the challenges to BIM adoption in the AECO sector. To improve BIM adoption in Egypt and other developing countries, the theoretical constructs from this study offer a mathematical framework for identifying the practical impediments that must be removed.

The study also offers the following conceptual and empirical contributions to this area of research:

- The study provides a conceptual contribution to this field by recognizing and conceiving new concepts to be incorporated into the conceptual framework, such as the effect of OSS installation obstacles on BIM.
- Although there is a lack of research on BIM deployment in Egypt, many studies exist from industrialized nations. This gap has been closed by the current study's examination of the significant obstacles to BIM adoption regarding the OSS.
- The study's final product, the model, is the first predictive model created in the building sector to assess how constraints to BIM deployment affect the OSS in the AECO sector. This technology is expected to catalyze BIM deployment in underdeveloped nations. This contribution is empirical, since it focuses on examining the theoretical relationships between two constructs—the "OSS" and "BIM implementation barriers"—that have not been examined in the previous research.

5.5. Managerial Implications

Building professionals may use the following managerial implications to assess how BIM implementation hurdles affect the OSS throughout a project:

- It aids decision-making when analyzing BIM obstacles' effects on the OSS.
- It results in significant barriers for AECO businesses that may be removed to solve the problems and hurdles connected with BIM adoption, boosting customer satisfaction through high-quality visualization.

5.6. Limitations and Future Research Suggestions

While this study contributes to the knowledge on the impact of BIM barriers on the OSS, it has several limitations. First, the study is limited in terms of geographical location. The research instrument (questionnaire) was only administered to construction professionals in Egypt. Future studies should seek to explore other regions to improve the generalization of the study. The second limitation is related to the cross-sectional nature of the survey research. This does not capture some aspects related to the organizations and historical contexts within the implementation of BIM. Therefore, future research could be longitudinal to draw causal inferences between BIM implementation drivers and OSS. Lastly, this study explores the impact of BIM barriers on the OSS using structural equation modeling (SEM) with theoretical conceptualization. Future studies could use innovation diffusion theory to understand the extent of BIM across a project's lifecycle.

6. Conclusions

A strong statement has been made against the poor caliber of building projects completed in developing nations, notably in the Egyptian building sector. Additionally, this study has demonstrated that BIM is a workable strategy for reducing this risk. However, this strategy is still not widely used in the building sector of underdeveloped nations. The quantitative research for this study was conducted in Egypt using a questionnaire survey. A PLS-SEM technique was used in this research to introduce an experimentally validated model using participants that were Egyptian building industry experts. The model's output will help building stakeholders to overcome the challenges that prevent BIM deployment. This study will lower expenses and raise success rates in Egypt and other developing nations. The findings of this study will also help developers to understand that BIM training must continue to deliver building projects that satisfy clients and boost consumer confidence in the sector. Although these results only apply to Egypt's BIM barrier

application research, they can be applied to other developing nations that share Egypt's unique characteristics, but lack comparative investigations.

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