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# Building Information Modeling Impact on Cost Overrun Risk Factors and Interrelationships

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**Abstract:** Building Information Modeling (BIM) has arisen as a promising technology that can enhance construction project outcomes through cost reduction when compared to conventional practices. More studies need to be conducted to examine the influence of BIM technology on cost overruns. Therefore, the primary aim of this paper is to investigate how BIM influences critical risk factors related to cost overruns. This investigation involves reevaluating and reranking these risk factors while exploring their interrelationships. Research involves a comprehensive literature review to identify risk factors correlated with cost overruns, the development of a survey questionnaire for BIM specialists, and an analysis of quantitative data using a partial least square structure equation model (PLS–SEM) to identify and examine significant risk factors and their interdependencies. The study's findings revealed that BIM significantly mitigates the impact of risk factors associated with the awarding of contracts to the lowest bidder, decreasing its ranking from first to third. Furthermore, BIM effectively minimizes the influence of risk factors related to changed orders, relegating it from second position to tenth position. In addition, risk factors related to experience exerted a more significant influence on risk factors related to finances than the influence of finances on experience. Findings contribute to the knowledge base by evaluating the influence of BIM technology on risk factors and cost overruns in the Saudi construction industry, thereby offering insights for improved project management and control.

**Keywords:** PLS–SEM; cost overrun; interdependencies; BIM; risk factors

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## 1. Introduction

Construction cost overruns are one of the most common problems the construction industry faces worldwide, and Saudi Arabia's construction projects are not exempt. Among the numerous adverse effects of these delays are a decreased percentage of completed projects, project abandonment, and project cancelations [1]. These factors have budgetary implications or cause additional expenditures [2,3]. This phenomenon has prompted academics and professionals to analyze the contributing risk factors. Conventional studies on construction projects have found the primary reasons behind project cost overruns and delays, which can be classified into four categories: project, people, environment, and management [4]. Building Information Modeling (BIM) studies, such as that by Sarvari et al. [5], have shown that BIM can aid in faster completion of construction projects with higher quality, lower costs, fewer errors, and lesser time loss than conventional construction practices. BIM has become standard in many industrialized nations, including the US, the UK, and Scandinavian nations, including Norway, Finland, and Denmark [5]. Parsamehr et al. [6] suggested that increasing interest in BIM technology among nations and academic communities is a positive indicator for managing and controlling the above problems.

Concerning conventional construction practices, considerable attention has been paid to risk factors related to the construction industry's delays and cost overruns. Moreover, many studies in BIM literature focus on factors contributing to delays (e.g., [3,7,8]), cost overruns (e.g., [9]), or both (e.g., [5]). However, there is minimal discussion on how BIM technology affects the performance of risk factors studied in conventional processes and their subsequent effects on cost overruns in Saudi construction projects. This study uniquely examines the impact of BIM adoption on 12 critical risk factors associated with project cost overruns. While most BIM research focuses on the direct effects of BIM on project costs, it often overlooks how this technology influences the risk factors contributing to cost overruns, underscoring BIM's potential to mitigate these key risks. Additionally, the study offers a detailed exploration of the interrelationships among these risks using PLS–SEM, a less common methodology in this field, providing deeper insights into the complex dynamics of risk factors.

Therefore, this study aims to examine the impacts of BIM use on critical risk factors linked to construction cost overruns in the Saudi construction context. To achieve this, various objectives were proposed:

1. to determine critical risk factors associated with construction cost overruns worldwide, particularly in the Saudi context;
2. to assess the influence of BIM usage on these identified risk factors within the Saudi construction industry;
3. to explore the relationships and interdependencies between significant risk factors in the context of BIM-enabled construction projects.

This study contributes to the knowledge base by examining the contribution of BIM technology to the Saudi construction industry by evaluating its influence on risk factors associated with construction project cost overruns. In addition, the application of PLS–SEM, a less common methodology in this field, brings a unique analytical perspective, allowing for a deeper exploration of interactions among risk factors. This approach provides a nuanced understanding of how these risks influence one another, offering a comprehensive view of costs within Saudi construction projects. The insights gained from this study are valuable not only for local stakeholders but also for international partners and stakeholders.

## 2. Literature Review

### *2.1. Cost Overruns in Saudi Arabia's Construction Projects*

The Economic Co-operation and Development Organization reported that Saudi's economy was predicted to grow at the highest rate among G-20 nations in the year 2022 and the following year 2023 [10]. Trading Economics (2022) reported that Saudi's gross domestic product (GDP) would increase from 7 billion USD in the second quarter of 2022 to 8 billion USD in the third quarter [10]. However, the Saudi construction industry still experiences budget exceedance and delays in construction projects for various reasons. This has negatively affected the development and performance of construction companies in Saudi. To improve this industry performance, in-depth studies since 1995 have revealed factors that contributed to a negative image for the Saudi construction industry [11–13]. Notably, several studies have investigated the reasons underlying project delays [11,13], while others have examined the causes of cost overruns (e.g., [9]), with some studies examining both (e.g., Alshihri et al. [14]). For example, a study by Assaf et al. [15] uncovered the leading causes of construction delays in Saudi from the contractors' perspective. Causes include delayed payments, underestimated project costs, legal issues, poor communication among project participants, underestimated project completion times, and delayed instructions received due to lack of supervision, owners and consultants. Another study by the same author discovered that approximately 70% of all public sector building projects had been delayed for several reasons [11]. Al-Kharashi and Skitmore's study [13] identified the five most common causes of delays, all related to contractors, ranked in the following order: insufficient skilled labor, lack of labor, delayed material delivery, supply shortage, and lack of project planning and coordination.

Alghonamy [9] surveyed forty-three contractors to determine risk factors associated with cost overruns and their importance to contractors. According to the results, the leading causes of building project cost overruns are the selection of the lowest bidders, numerous design changes, inadequate planning, long delays between design and execution phases, and payment delays. In addition, concerning University Campus construction projects (UCP), Alzara et al. [16] found that delays ranged from 50% to 150% for (UCP), and 99% of (UCP) exceeded expected costs.

Likewise, Al-Emad et al. [17] surveyed Makkah's construction projects with 100 experts, revealing ten leading causes of delays. These factors include financial problems caused by contractors, lack of coordination among project stakeholders, shortage of labor, design document production delays, ineffective scheduling and planning, payment delays, low levels of labor productivity, lack of communication among project parties, inexperienced labor, and lack of contract management. Here, former risk factors associated with project delays resulted in additional expenses.

To recognize the significant factors that contribute to cost overruns, a quantitative study by Alshihri et al. [14] aimed to identify and investigate critical risk factors that affect construction projects' cost overruns. Based on a comprehensive literature review, 83 risk factors were identified and classified into nine categories. Survey findings revealed the top ten risk factors. These factors are each ranked respectively as follows: (1) contractor financial issues, (2) payment delays, (3) awarding contracts to the lowest bidder, (4) changing orders during construction, (5) inadequate project scheduling and planning by contractor, (6) lack of workforce, (7) lack of construction site supervision and management by contractor, (8) lack of skilled contractors, (9) delays in subcontractor or supplier work, and (10) lack of experienced workers. In a recent study, the main factors leading to construction project delays were poor contract management, inaccurate planning, lack of skilled employees, delays in decision-making, and cost challenges, according to Alajmi et al. [18].

These studies show that cost overruns in Saudi projects have long been a problem that has impacted the image of the construction sector. As the Saudi construction industry experience is also close to those of developed countries, there is a significant need for collaboration among stakeholders to complete projects on time (Alenazi et al. [7]). Furthermore, Alshihri et al. [14] reviewed and ranked significant risk factors contributing to cost overruns in conventional practices (without considering the use of BIM in construction activities) in Saudi construction projects. In this context, the current study is based on the 12 factors that cause most problems.

### *2.2. Risk Factors Related to Construction Project Cost Overruns in BIM Context*

Numerous risk factors contribute significantly to construction project cost overruns. A vital issue is that of the frequent changes occurring during the construction phase, leading to schedule disruptions and inadequate monitoring, as observed in Indonesian construction projects [19]. These challenges are compounded by deficient financial control, inadequate supervision, and logistical hurdles, like shipping delays and equipment shortages [19]. In design and build (D and B) projects, continual design alterations stemming from incomplete initial drawings and on-site errors significantly contribute to cost overruns, aggravated by contractors' inefficient planning and scheduling [20]. BIM is vital in mitigating these risks through enhanced interoperability, clash detection, and digitalized quantity assessments, improving planning accuracy and reducing uncertainties [20].

An upsurge in BIM-related research over the last five years indicates a growing interest among construction management researchers in understanding the implications of BIM [6]. This shift marks a positive trajectory in the construction sector, moving away from the perception that BIM was primarily used for promotional purposes and client negotiations [21]. Studies have demonstrated significant cost benefits associated with BIM implementation in construction projects. For instance, Ghaffarianhoseini et al. [22] and Latiffi et al. [23] have highlighted various advantages of BIM, such as technical prowess, improved scheduling, enhanced decision-making support, and economic benefits. BIM's

integration has led to expedited decision-making, early conflict detection in the design phase, reduced design time, and enhanced data integrity, all crucial in mitigating cost overruns and enhancing project efficiency [24].

Moreover, Doumbouya et al. [25] underscore how BIM facilitates effective decision-making and execution across all project phases, offering tools for tracking project progress during construction and enabling swift remote assessments of construction performance. Despite its innovative potential in the architecture, construction, and engineering (ACE) industries, BIM still needs to be utilized further [26]. Recent findings by Tahir et al. [27] from a BIM study in a developing country's construction industry suggest that increased BIM usage correlates with reduced project delays and reduced cost overruns. These insights underscore the transformative potential of BIM in enhancing construction project management and efficiency.

### 2.3. PLS–SEM

PLS–SEM is an effective technique that may be used to diagnose complicated models with several latent groups and observable indicators. It makes it easier to estimate the inner model, which evaluates relationships between various latent groups, and the outer model, which captures associations between latent groups and their indicators. Figure 1 displays the components of a simple PLS–SEM model, and also shows a PLS–SEM model with two latent groups (A and B). Group A has three indicators (A1, A2, and A3). At the same time, group B has two indicators (B1 and B2). In this example, group A impacts group B (A→B). Therefore, group A is exogenous, and group B is indigenous. The relationship between group A with its indicators (A1, A2, and A3) and the relationship between group B with its indicators (B1 and B2) represent the outer model. At the same time, the relationship between group A and group B is the inner model, as shown in Figure 1. This adaptability is particularly useful when examining complicated causal interdependencies across different groups [28]. PLS–SEM also enables researchers to find significant factors, propose new ideas for investigation, and examine interactions and patterns within data. Adaptability and handling small sample sizes make it suitable for exploratory research [29]. Various studies extensively utilize PLS–SEM to assess risks across different sectors. For instance, Wong Chin Yew et al. [30] employed PLS–SEM to explore the relationship between safety risks and mitigation steps in the Malaysian construction sector. Other previous studies have not utilized PLS–SEM to assess risk factors of cost overrun in construction projects that incorporate BIM during construction. More research is needed to examine interdependencies and influences among significant risk factors in this context.

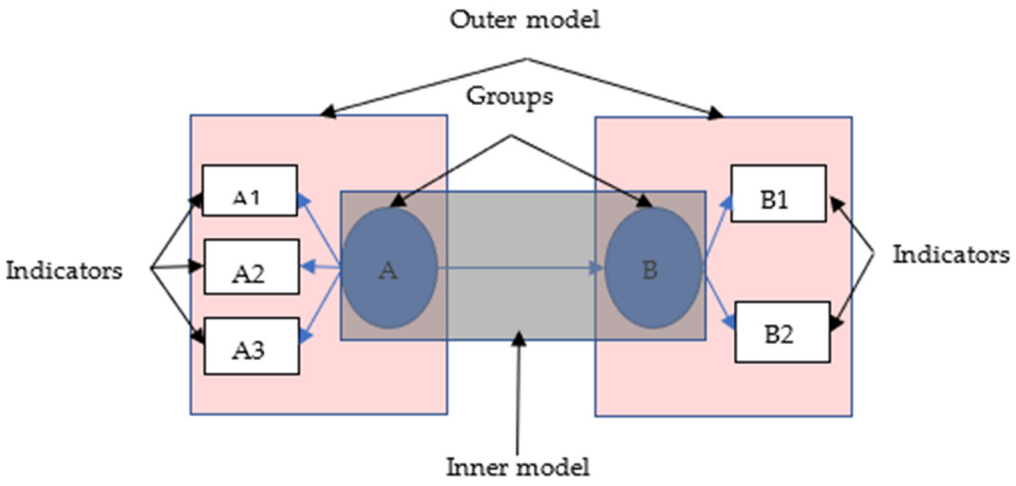



**Figure 1.** Components of a simple PLS–SEM model.

## 3. Methodology

The methodology used in this study contains three key steps and sub-steps (Figure 2). First, the literature collects data on significant risks causing overruns in construction projects without BIM in Saudi Arabia. These data provide a baseline understanding of risks prevalent in traditional project implementation. Second, a semi-structured interview was conducted with five BIM experts from the Saudi construction industry, each with over eight years of experience. The purpose was to identify the potential effects of BIM adoption on the top 12 risk factors associated with project cost overruns, which was highlighted in Alshihri et al.'s study. Third, a pilot survey was conducted with 26 experienced BIM professionals to ensure the reliability and validity of the survey results. Finally, the main survey study was conducted to assess the influence of these risks on cost escalation while considering the utilization of BIM during the project implementation phase. The survey captures the perceptions of industry professionals and stakeholders with BIM experience. Third, an analysis of survey data identifies and prioritizes the most significant risk factors associated with cost overruns with BIM implementation, and studies potential interactions between these risk factors. The statistical method known as PLS–SEM is implemented in this analysis. PLS–SEM allows for a comprehensive examination of relationships and dependencies among identified risk factors by performing hypothesis testing of those relationships, providing valuable insights into their combined effects on cost overruns when BIM is adopted.

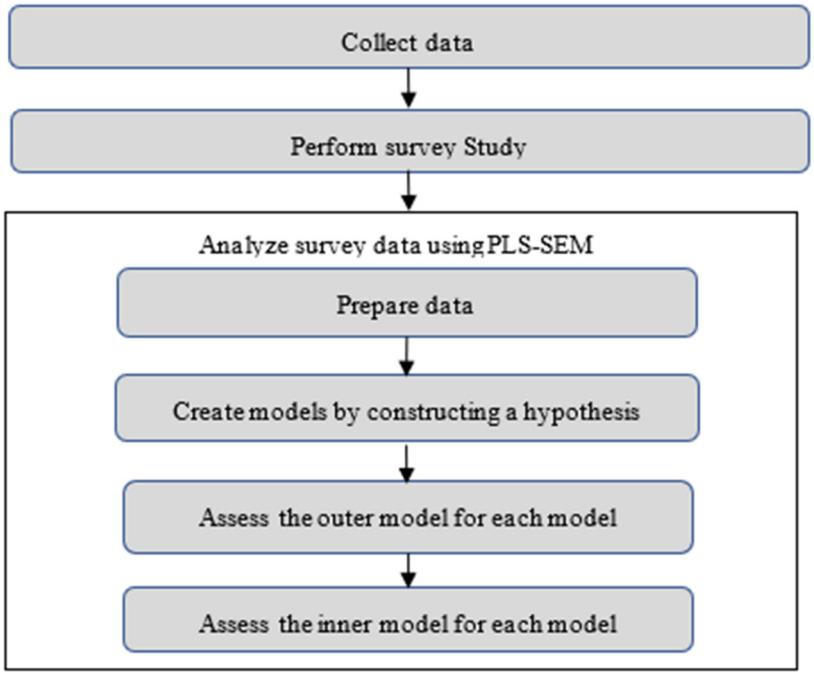



**Figure 2.** Methodology flow chart.

### *3.1. Collect Data*

The first step is to review the literature in order to identify the top 12 cost overrun risk factors in non-BIM construction projects within the Saudi context. Consequently, 12 risks identified from Alshihire et al.'s study [14] were classified into Financial, Time, and Experience. Table 1. shows the 12 risk factors and their classification. This step provides a baseline understanding of risks prevalent in the traditional construction process.

**Table 1.** Significant risk factors for cost overrun without using BIM.

| No | Risk | Symbol | Group |
|---|---|---|---|
| 1 | Insufficient leadership skills and contractor expertise | EXP1 | Experience |
| 2 | Absence of site monitoring and supervision by contractors | EXP2 | |
| 3 | Lack of skilled/experienced laborers | EXP3 | |
| 4 | Inconsistent and insufficient specifications, bills of quantities, and drawings | EXP4 | |
| 5 | Contractor's expense challenges (i.e., ineffective cash flow management) | FIN1 | Financial |
| 6 | Owner's delays in payment for completed tasks | FIN2 | |
| 7 | Award of contract to the lowest bidder | FIN3 | |
| 8 | Change orders over the construction stage | FIN4 | |
| 9 | Lack of an effective contractor's planning and scheduling | TIM1 | Time |
| 10 | Delays in works by suppliers/subcontractors | TIM2 | |
| 11 | Unreasonable or insufficient original contract length | TIM3 | |
| 12 | Slowness in decision-making process approvals | TIM4 | |

### 3.2. Perform Survey Study

The second step involved surveying to gather insights from industry professionals and stakeholders regarding their perceptions of and experiences with BIM. Due to the dynamic process of BIM differing from the traditional method of managing construction projects, and to ensure that the participants in the main survey would understand the questions, the following sub-steps were carried out: (a) Face-to-face semi-structured interviews were conducted with five BIM experts in the construction industry in senior positions (e.g., contractors, construction managers, supervision consultants, and BIM managers) with at least eight to ten years of experience of BIM construction projects, which helped to formulate (b) a first-draft questionnaire to elicit responses. After reviewing the BIM literature, applying a quantitative data collection method is the primary method with which to examine the influence of BIM technology on risk factors that contribute to cost overrun for Saudi construction projects. Typically, a questionnaire is used for this purpose (e.g., [2,5,31]). (c) A pilot web-based questionnaire was tested with 26 respondents (including project managers, construction managers, contractors, and BIM specialists). Using a five-point Likert scale, they were asked to rate the potential impact of using BIM on risk factors linked to cost overruns. Finally, (d) data were collected via a web-based questionnaire for the main study. A list of engineers' names and contact addresses was obtained from the Saudi Council of Engineers to guarantee distribution to a random sample. A web-based questionnaire link was sent via email to several relevant AEO firms and via the Saudi Council of Engineers, requesting participation and encouraging the link to be shared with other professionals. The questionnaire was distributed to 300 participants. Sixty-two responses were received, 60% from experienced BIM professionals. No additional responses were received, and 30 complete responses were retained for analysis after excluding 32 incomplete applications and applications from participants with no BIM experience. Since the population size was unknown, we assumed an infinite population, allowing us to determine the sample size using Equation (1) [32]:

$$sample\ size = \frac{Z \times p \times (1-p)}{C^2} \quad (1)$$

where the sample size was 30, the $Z$ value equals 1.65 for a confidence level of 90%, $p$ represents the probability of the choice represented as a decimal and chosen as 0.5. $C$ is the confidence interval, and should be less than 0.2. Based on Equation (1), this study shows that the $C$ value is 0.12, less than 0.2. Hence, the sample can be accepted [32,33].

The questionnaire consists of two parts. The first represents the participant's demographic information. The second contains questions on the rate of potential impact of using BIM on risk factors related to project cost overrun (shown in Table 1) using a five-point Likert scale. Table 2 presents detailed information regarding the participants' experiences,

their roles in the building project, and supplementary details relevant to each participant. It is worth noting that more than 48% of survey participants were experienced BIM specialists with over five years of experience, with almost 52% with less than 5 years. Table 3 shows the survey data.

**Table 2.** Descriptive examination of the research sample's demographic information.

| Demographic Data | | | Descriptive Analysis % |
|---|---|---|---|
| **Section** | **Item** | **Responses** | |
| office Information | What is the activity of the office you work for? | Construction office | 23.21 |
| | | Consultancy and Project Management office | 51.79 |
| | | Maintenance and Operation office | 0 |
| | | Operation and Construction office | 8.93 |
| | | If another, kindly mention | 16.07 |
| | Which sector does the office belong to? | Private companies | 64.29 |
| | | Public–governmental companies | 30.36 |
| | | If another, kindly mention | 5.36 |
| | What is your office's role in the construction project? | Customer | 19.64 |
| | | Project Director | 26.79 |
| | | Design Consultant | 21.43 |
| | | Supervision Consultant | 12.50 |
| | | Contractor | 19.64 |
| Personal Information | What role do you play in building projects? | Construction Director | 9.30 |
| | | Site Engineer | 4.65 |
| | | Technical Director | 9.30 |
| | | Technical Office Engineer | 11.63 |
| | | BIM Director | 25.58 |
| | | BIM Specialist | 6.98 |
| | | BIM Coordinator | 9.30 |
| | | Quality Control Engineer (QCE) | 6.98 |
| | | Project Control Engineer (PCE) | 0.00 |
| | | Planner | 2.33 |
| | | Quantity surveyor (QS) | 0.00 |
| | | Contracts Director | 6.98 |
| | | If another, kindly mention | 6.98 |
| | How many years of experience do you have using BIM technology to implement construction projects? | 1–5 | 51.79 |
| | | 6–10 | 17.86 |
| | | 11–15 | 17.86 |
| | | +15 years | 12.50 |

**Table 3.** Hypothesis statements for the seven models.

| Model | Index | Hypothesis Statement | Path |
|---|---|---|---|
| Model 1 | H1 | Financial risk factors group influences cost overrun | Financial → cost overrun |
| | H2 | Experience risk factors group influences cost overrun | Experience → cost overrun |
| | H3 | Time risk factors group influences cost overrun | Time → cost overrun |
| Model 2 | H1 | Financial risks factors group influences experience risks factors group | Financial → Experience |
| | H2 | Experience risk factors group influences cost overrun | Experience → cost overrun |
| | H3 | Time risk factors group influences cost overrun | Time → cost overrun |

**Table 3.** *Cont.*

| Model | Index | Hypothesis Statement | Path |
|---|---|---|---|
| Model 3 | H1 | The financial risk factors group influences time risk factors group | Financial → Time |
| | H2 | Experience risk factors group influences cost overrun | Experience → cost overrun |
| | H3 | Time risk factors group influences cost overrun | Time → cost overrun |
| Model 4 | H1 | Financial risk factors group influences cost overrun | Financial → cost overrun |
| | H2 | Experience risk factors group influences financial risk factors group | Experience → Financial |
| | H3 | Time risk factors group influences cost overrun | Time → cost overrun |
| Model 5 | H1 | Financial risk factors group influences cost overrun | Financial → cost overrun |
| | H2 | Experience risks factors group influences time risks factors group | Experience → Time |
| | H3 | Time risk factors group influences cost overrun | Time → cost overrun |
| Model 6 | H1 | Financial risk factors group influences cost overrun | Financial → cost overrun |
| | H2 | Experience risk factors group influences cost overrun | Experience → cost overrun |
| | H3 | Time risk factors group influences financial risk factors group | Time → Financial |
| Model 7 | H1 | Financial risk factors group influences cost overrun | Financial → cost overrun |
| | H2 | Experience risk factors group influences cost overrun | Experience → cost overrun |
| | H3 | Time risk factors group influences time risk factors group | Time → Experience |

### *3.3. Analyze Survey Data Using PLS–SEM*

Analysis of survey data using the PLS–SEM method involves a systematic process encompassing four distinct stages, as shown in Figure 2. Data are meticulously prepared and processed in the first stage to address any missing or incomplete information, ensuring that the dataset is complete and accurate for subsequent analysis. Multiple models are constructed by formulating various hypotheses that capture the relationships between different risk factors within each model. These hypotheses serve as frameworks to explore and assess interdependences among risk factors. The third stage involves conducting outer assessments of each model regarding construct and discriminant validities. Finally, in the fourth stage, inner assessments were carried out. Here, the focus shifts to hypothesis tests of relationships among group risk factors for each model.

#### 3.3.1. Prepare Survey Data

The answers of the 30 participants for the second part of the questionnaire were collected and entered into MS Excel. Then, these answers were coded by replacing very low, low, medium, high, and very high with 1, 2, 3, 4, and 5, respectively. When a participant responded to a question with two choices, answers were regarded as missing data that required analysis with IBM SPSS Statistics 20 software. Two categories of unusual information were identified based on participants' answers. The first type consisted of participants selecting multiple Likert scale points, while the second type involved unanswered questions (missing data). SPSS offers several methods to handle missing data. The mean nearby point method was employed in this study. After treatment in the SPSS application, data were imported to an MS Excel file for further processing.

#### 3.3.2. Create Models by Constructing a Hypothesis

This section aims to determine the number of required models to identify significant risks, examine interdependencies among groups' risk factors, and then create a necessitated hypothesis for each model. Three groups (Experience, Financial, and Time) were used to determine the number of required models. Therefore, the required number was a factorial 3 ($3! = 3 \times 2 = 6$), making six models. In addition, there was an additional model to examine the direct relationship between the three groups and the cost overrun group. Therefore, the total number of models was seven. Each model had three relationships (hypotheses), represented by an arrow motion from one group to another. Seven models are shown with their relationships (Figure 3). Hypothesis statements for each model are given in Table 3. Model 1's objectives were to determine key risk factors and evaluate the direct impact of Time, Experience, and Finance on cost overruns. Other than that, Models 2, 3, 4, 5, 6, and 7 examined the impact of associations among the three risk factors groups (Financial,

Experience, and Time). The cost overrun group is an Indigenous latent group, whereas the three groups in Model 1 are exogenous latent groups. To investigate the impact of the financial risk factors group (Financial) on the experience risk factors group (Experience), Model 2 (Figure 3) was run.

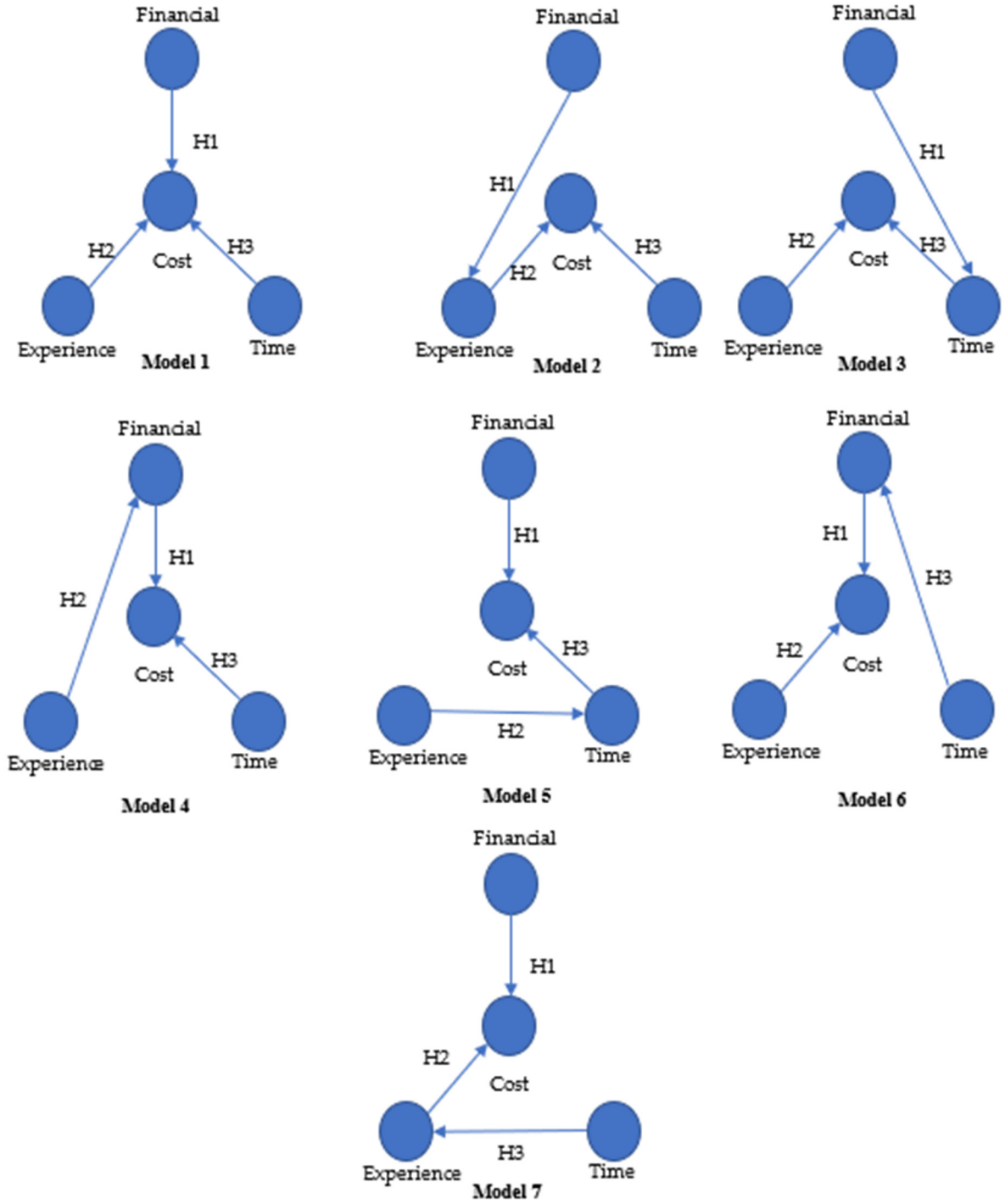



**Figure 3.** Seven models' structure.

Consequently, experience and cost overruns belong to the indigenous group, whereas the financial and time groups are exogenous. Additionally, Model 3 was used to examine how the financial risk factors group affected the time risk factors group. Therefore, Financial and Experience factors are considered exogenous in this context. The purpose of Model 4 and Model 5 is to explore how risk factors related to experience interact with those related

to finance and time, respectively. Thus, Financial and cost overruns are indigenous groups in Model 4, while Time and cost overruns are inherent to Model 5. Furthermore, Model 6 and Model 7 seek to analyze how risk factors associated with time affect financial and experience factors, respectively.

#### 3.3.3. Evaluate Outer Model

For each model, the assessment of the outer model focuses on identifying and removing insignificant risk factor variation. Construct validity and discriminant validity were performed. Construct validity investigates indicators (risk factors) that positively contribute to their group. Magnitudes of Cronbach's alpha (α), composite reliability (CR), and average variance extracted (AVE) were calculated for the three groups. Outer loading of risk factors influences the reliability coefficients of constructs. Values of α, CR, and AVE are associated with the outer loading of risk factors. The α and CR can be estimated using Equations (2) and (3), respectively.

$$\alpha = \left(\frac{M}{M-1}\right)\left(1 - \frac{\sum_{i=1}^{M} {s_i}^2}{s_t^2}\right) \tag{2}$$

$$CR = \frac{\left(\sum_{i=1}^{M} l_i\right)^2}{\left(\sum_{i=1}^{M} l_i\right)^2 + \sum_{i=1}^{M} var(e_i)} \tag{3}$$

The variance of $a$ risk factor is denoted by $s_i^2$, while $s_t^2$ signifies variance linked to observed total factors within a specific group. The standardized outer loading value of the $i$th risk factor in a group is represented by $l_i$ M, which represents a number of factors within a group, and $var(e_i)$ indicates variance attributed to measurement errors.

Additionally, the purpose of $AVE$, which can be calculated utilizing Equation (4), is to evaluate the degree to which risk factors of a latent group share common variance and reflect underlying constructs. This provides information about convergent validity, which is the degree to which construct risk factors are related to each other and converge onto latent groups. It will be higher than the accepted level value (0.50) by omitting the risk factor with the lowest outer loading ($l$) value [34].

$$AVE = \frac{\sum_{i=1}^{M} l^2}{M} \tag{4}$$

Aljarallah et al. [35] summarized the construct validity steps followed in this paper;

1. Choose a specific group (Financial, Experience, or Time).
2. Display outer loading values for factors within that group.
3. Remove any factors with an outer loading value below 0.4.
4. Evaluate the removal of factors with outer loading values between 0.4 and 0.7.
5. A factor is removed if elimination leads to enhancements in the group's α, CR, and AVE; otherwise, the factor is retained.
6. Repeat these steps for the remaining factors until Cronbach's α and CR exceed 0.7 and AVE surpasses 0.5.

Crucial metrics for assessing discriminant validity are cross-loadings and the Fornell–Larcker criterion. The Fornell–Larcker criterion can be determined if a group contributes higher variance with itself than other groups. To meet this requirement, $AVE^2$ for each group must be greater than the covariance between that group and the other group [36]. According to the cross-loading method, a risk factor should load more with the corresponding group than any other group [36].

3.3.4. Evaluate the Inner Model

Assessing the inner model aims to examine proposed interdependencies between different groups and comprehend how they affect one another. The hypothesis relationship is examined by determining the *p*-value depending on the standard error magnitude obtained via bootstrapping in SmartPLS (v.3.2.9) software. These values determine how the hypothesis test turns out. If the coefficient for the *t*-value is greater than the significance level, it is considered statistically significant. A 5% confidence level is commonly used by researchers when evaluating hypotheses. A significance level of 5% was used in this investigation. The *t*-value is 1.96 or higher. In that instance, the alternative hypothesis, which suggests a relationship between two groups, b $\neq$ 0—, is accepted, and the null hypothesis, which suggests no relationship between groups, b = 0—, is rejected.

## 4. Results and Discussion

### *4.1. Significant Cost Overrun Risk Factors Using BIM*

The main purpose of outer model evaluation is to recognize and remove insignificant risk factors. Upon conducting an outer evaluation of seven models, it was observed that the results of the outer evaluation were consistent across all seven models. Therefore, findings from the outer evaluation of the first model are deemed sufficient.

Figure 4 illustrates significant factors and their corresponding outer loading values, which satisfy construct and discriminant validity criteria. Regarding construct validity, Table 4 presents values for Cronbach's Alpha, CR, and AVE for three groups. These values surpass acceptable thresholds of 0.7 for both Cronbach's Alpha and CR, as well as 0.5 for AVE, thereby validating the model's construct validity.

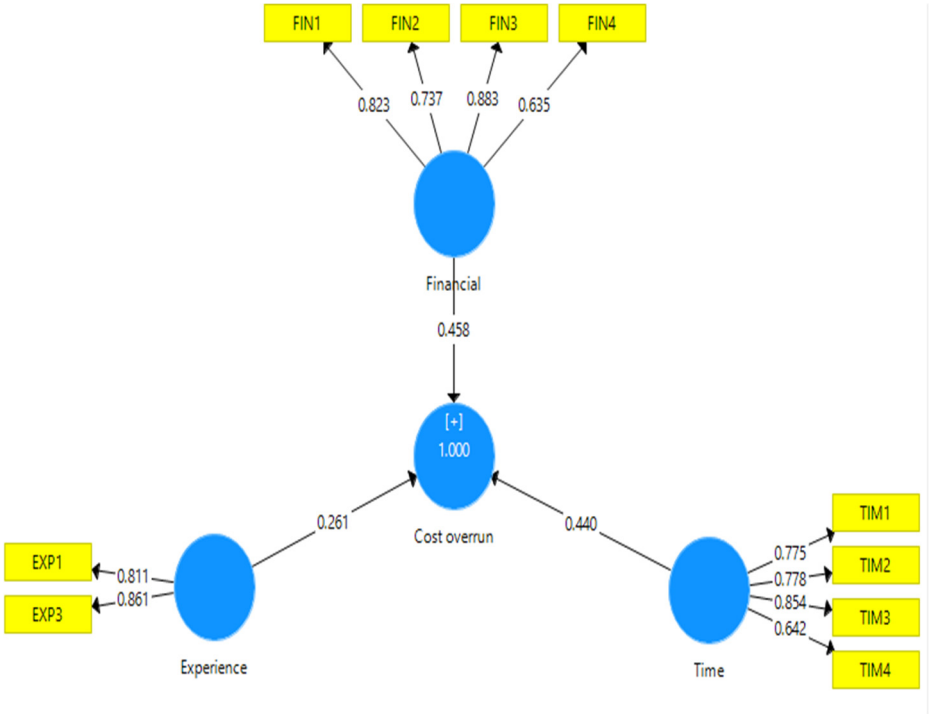



**Figure 4.** Outer loading of risk factors in Model 1.

**Table 4.** Construct validity.

| | Cronbach's Alpha | *CR* | *AVE* |
|---|---|---|---|
| Experience | 0.571 | 0.823 | 0.699 |
| Financial | 0.778 | 0.856 | 0.601 |
| Time | 0.763 | 0.849 | 0.587 |

Moving on to discriminant validity, Table 5 displays the Fornell-Larcker criterion, showcasing discriminant validity among groups. The square root of AVE for each group (found at the intersection of row and column for the same group in Table 5) exceeds correlation coefficients between that group and other groups. This result confirms the presence of discriminant validity.

**Table 5.** Fornell–Larcker Criterion of Model 1.

| | Experience | Financial | Time |
|---|---|---|---|
| Experience | 0.836 | | |
| Financial | 0.669 | 0.775 | |
| Time | 0.641 | 0.551 | 0.766 |

Additionally, the cross-loading value is used to assess discriminant validity. This indicates how strongly an indicator (risk factor) correlates with its associated group construct compared to other groups. Table 6 provides cross-loading values between risk factors and three groups. The cross-loading values for risk factors within their respective groups are higher than those with other groups, as indicated by shaded cells in Table 6.

**Table 6.** Cross-loading values of risk factors and groups.

| | Experience | Financial | Time |
|---|---|---|---|
| EXP1 | 0.811 | 0.594 | 0.398 |
| EXP3 | 0.861 | 0.530 | 0.658 |
| FIN1 | 0.714 | 0.823 | 0.469 |
| FIN2 | 0.256 | 0.737 | 0.335 |
| FIN3 | 0.721 | 0.883 | 0.524 |
| FIN4 | 0.217 | 0.635 | 0.343 |
| TIM1 | 0.687 | 0.454 | 0.775 |
| TIM2 | 0.438 | 0.558 | 0.778 |
| TIM3 | 0.490 | 0.342 | 0.854 |
| TIM4 | 0.298 | 0.299 | 0.642 |

An inner model assessment was conducted to identify and rank significant risk factors. This assessment involved performing hypothesis tests on Model 1. Results revealed that *p*-values of H1, H2, and H3 were below threshold value, indicating that all three hypotheses were accepted and suggesting that the three groups examined significantly impact cost overrun. Furthermore, weight loadings of the remaining ten risk factors were normalized and ranked in descending order, as depicted in Figure 5. The two highest-ranked risk factors were EXP3 and EXP1, indicating their strong influence. Several intermediate significant risk factors were identified, including FIN3, FIN1, TIM1, TIM2, and TIM3. On the other hand, the remaining risk factors (FIN2, TIM4, and FIN4) exhibited lower significance levels.

The risk factor of unqualified or inexperienced labor (EXP3) significantly influences cost overrun when using BIM in the construction stage of a project due to several interconnected reasons. Firstly, lack of knowledge and experience among human resources is identified as one of the most critical risks impacting cost overruns, as it directly affects the efficiency and accuracy of project execution [37]. Inadequate supervision and poor management at the site, which are often consequences of employing unqualified labor, further exacerbate this issue by leading to frequent changes and delays during construction [19].

The risk of a lack of contractor experience and managerial skills (EXP1) significantly influences cost overrun during the construction stage of a project, even when using BIM, due to several interconnected factors. Firstly, while BIM technology offers substantial benefits in project visualization, coordination, and delay reduction, its effectiveness depends on user proficiency. Inexperienced contractors may need help in fully leveraging BIM's capabilities, leading to suboptimal project management and cost control [38]. Additionally, a lack of managerial skills can exacerbate issues such as inadequate control and monitoring, poor

finance control, and insufficient supervision, all of which are critical factors contributing to cost overruns [19].

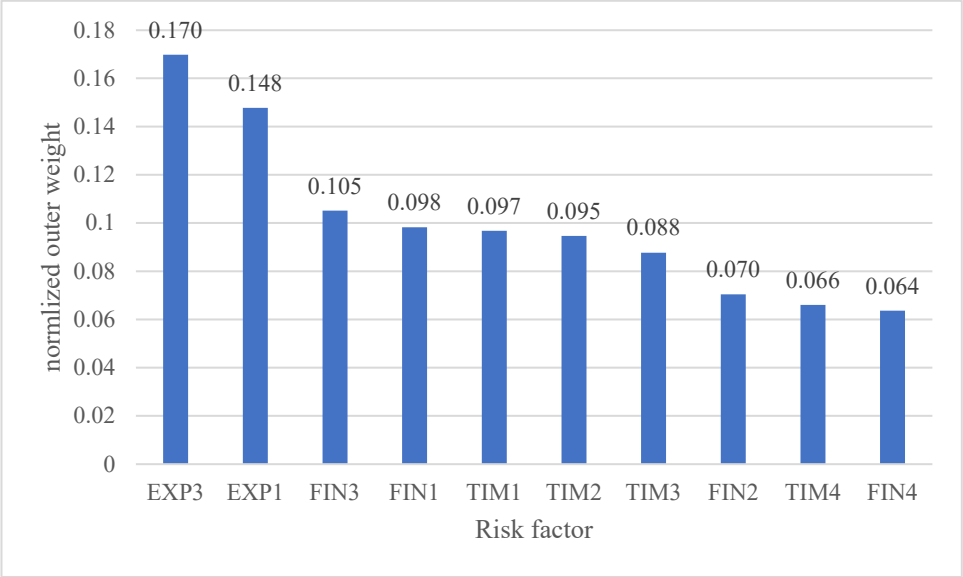



**Figure 5.** Normalized weight loading of risk factors.

The study's findings diverge from those of Alshihiri et al. [14], who ranked FIN3 and FIN4 as the top two factors. This difference can be attributed to two key causalities. Firstly, Alshihiri et al. [14] examined risk factors associated with a cost overrun without considering the impact of utilizing BIM during the implementation phase on these factors. In contrast, this study considers the influence of BIM usage, leading to differing results. Secondly, the statistical methods employed in this paper differ from those used by Alshihiri et al. [14]. Alshihiri et al. [14] utilized the relative importance index method, while this study adopted the PLS–SEM method. In addition, the participants differed in the current paper and that of Alshihiri et al. [14]. However, the difference in statistical methods and participants has a minor effect on the results.

### *4.2. Interdependence Influence Among Risks Factor Groups*

This section focuses on verifying mutual relationships among groups of risk factors that affect project cost overrun and identifying the most influential relationships if they exist. Table 7 displays *p*-values and b-coefficients for three relationships across seven models. Notably, all *p*-values are below 0.05 (at a 95% confidence level), indicating that all relationships are statistically significant, i.e., they exist. In essence, the presence of non-zero b coefficient values for each relationship results in rejecting the null hypothesis and accepting the alternative hypothesis. As a consequence, overlapping effects are observed among risk factor groups.

To determine the most influential between the two groups, b coefficient values are compared in opposite directions. For instance, the *p*-value for the influence of Financial on Experience is 0.501, while the *p*-value for the impact of Experience on Financial is 0.725. This result suggests that experience has a more significant effect on finances. Similarly, time has a slightly stronger influence than Financial. When examining interaction impacts between Experience and Time, it becomes apparent that time has a more significant effect on experience, as indicated by a b coefficient value of 0.695 for the relationship of Time on Experience, compared to a b coefficient value of 0.705 for the relationship of Experience on Time, as shown in Table 7.

These results suggest that risk factors associated with experience exert a more significant influence on financial risk factors than financial factors' impact on experience. Additionally, risk factors linked to time demonstrate a slightly stronger influence than financial

factors. In contrast, Time-related risks have a more pronounced effect on Experience-related risks than the reverse relationship of Experience on Time.

**Table 7.** Hypothesis statements for the seven models.

| Model | Index | Path | *p*-Value | B Coefficient |
|---|---|---|---|---|
| Model 1 | H1 | Financial → cost overrun | <0.001 | 0.459 |
| | H2 | Experience → cost overrun | <0.001 | 0.253 |
| | H3 | Time → cost overrun | <0.001 | 0.427 |
| Model 2 | H1 | Financial → Experience | <0.001 | 0.501 |
| | H2 | Experience → cost overrun | <0.001 | 0.752 |
| | H3 | Time → cost overrun | <0.001 | 0.569 |
| Model 3 | H1 | Financial → Time | <0.001 | 0.626 |
| | H2 | Experience → cost overrun | <0.001 | 0.498 |
| | H3 | Time → cost overrun | <0.001 | 0.569 |
| Model 4 | H1 | Financial → cost overrun | <0.001 | 0.607 |
| | H2 | Experience → Financial | <0.001 | 0.725 |
| | H3 | Time → cost overrun | <0.001 | 0.497 |
| Model 5 | H1 | Financial → cost overrun | <0.001 | 0.577 |
| | H2 | Experience → Time | <0.001 | 0.695 |
| | H3 | Time → cost overrun | <0.001 | 0.530 |
| Model 6 | H1 | Financial → cost overrun | <0.001 | 0.574 |
| | H2 | Experience → cost overrun | 0.001 | 0.470 |
| | H3 | Time → Financial | <0.001 | 0.630 |
| Model 7 | H1 | Financial → cost overrun | <0.001 | 0.598 |
| | H2 | Experience → cost overrun | 0.001 | 0.452 |
| | H3 | Time → Experience | <0.001 | 0.705 |

EXP3 (Lack of skilled/experienced laborers) and EXP1 (Insufficient leadership skills and contractor expertise) affect FIN1 (Contractor's expenses challenges). For instance, unqualified/inexperienced labor may lead to lower productivity and efficiency on construction sites, resulting in delays or rework, which can increase costs and potentially lead to financial difficulties for contractors. Moreover, unqualified laborers are more prone to accidents and injuries, which disrupt workflow and necessitate additional resources for recovery and rework [39]. Lack of contractor experience and managerial skills can affect overall project management, including budgeting, resource allocation, and financial planning, potentially contributing to financial challenges. Contractors' inefficiency often stems from inadequate supervision, lack of control over subcontractors, and poor planning and scheduling, resulting in delays and poor quality of work [40].

Concerning the impact of EXP3 and EXP1 on FIN2, it is evident that a workforce deficient in qualifications or experience can markedly affect work quality in construction endeavors, potentially resulting in disputes and project delays. In developing countries, constraints such as site location, lack of experienced laborers, and absence of policies governing recruitment and selection processes contribute to the employment of unqualified labor, affecting project delivery and quality [41].

On the other hand, Unqualified or inexperienced labor is often linked to contractors who submit lower bids to secure projects, a practice that can lead to significant inefficiencies and challenges in project delivery. This problem is especially pronounced in expanding countries where the lowest bid criterion is binding in public procurements, and contractors frequently exploit loopholes in bid process management systems [42]. Moreover, Insufficient labor qualifications or experience can lead to errors or misunderstandings during the construction phase, significantly increasing the likelihood of change orders. These change orders, often arising from discrepancies between design plans and actual field conditions, insufficient design details, and impractical execution complexities, can disrupt project timelines and inflate costs, thereby straining contractor's financial resources [43].

By examining these relationships and comparing b coefficient values, we gain insights into the interplay among different groups of risk factors and their relative importance in influencing cost overrun. This understanding can inform project management strategies and decision-making processes, allowing for more effective risk mitigation and resource allocation. The research findings can be extrapolated to apply to other countries that exhibit similar factors as those studied in the research

## 5. Conclusions

Construction projects suffer from change orders, scheduling conflicts, and cost overruns that result in additional project costs. These issues are attributed to several risk factors for which experts and academics have identified BIM technologies as innovative solutions [44]. Therefore, this study aimed to investigate the extent to which implementation of BIM technology mitigates the main risk factors related to cost overruns in Saudi construction projects. To do so, a survey study was conducted, collecting 30 valid and completed questionnaires from professionals in the construction industry. Collected quantitative data was analyzed using PLS–SEM to identify and examine significant risk factors and their interdependencies. It is important to note that this research focused only on examining the impact of BIM on the top 10 risk factors related to Experience, Finances, and Time, as comprehensively identified within the context of the Saudi construction industry, e.g., (Alshihri et al. [14]). Overall, the synthesis of the literature review and survey analysis findings showed that BIM significantly reduces cost overruns in construction projects compared to conventional construction processes. This positive influence is due to various benefits of BIM technology that help mitigate influential risk factors and consequent project cost overruns. This result aligns with existing studies, e.g., [25,45]. The main results revealed that BIM utilization substantially reduces the impact of risk factors associated with awarding contracts to the lowest bidder. This effect is evident in the decrease in its ranking from first to third place.

Moreover, BIM is highly effective in minimizing the influence of risk factors related to change orders, significantly dropping its ranking from second to tenth place. Moreover, the study sheds essential light on interrelationships among several cost overrun risk factors concerning Experience, Time, and Finance. For example, it has been found that experience-related risk factors have a more significant influence on finance-related risk factors than finance does on experience.

To the best of our knowledge, this paper is the first attempt in BIM literature to examine the cause and effect of BIM technology on risk factors linked to construction project cost overruns in general and the interrelationship influence between those factors using specific statistical analysis techniques (PLS–SEM). Moreover, it is difficult to understand the difference between the two processes, BIM and non-BIM. Therefore, this study helps to draw a line of comparison between the two processes by presenting the main risk factors associated with cost overruns that have been affected by BIM implementation. For example, BIM reduces the influence of change orders during the construction stage (FIN4) on cost overrun, compared with the low influence of BIM on Unqualified/inexperienced laborers (EXP3). Study results are consistent with BIM literature, which shows that BIM decreases the number of change orders during the construction phase (e.g., Azhar, [44]). Regarding

practical implications for practitioners and decision-makers, this study concludes that BIM technology is a better option for managing construction costs.

This study acknowledges the limitations inherent in relying on self-reported survey data, which is potentially subject to respondent bias. Moreover, the study could benefit from triangulating its findings with objective data or alternative statistical methods. Based on conclusions previously identified, the results of this research, and comments from interviews and questionnaire responses, the following points can be recommended. Comparative studies across diverse regions are advised to enhance the applicability of results beyond Saudi Arabia. Improving research validity and reliability can also be achieved by integrating objective data sources and employing various data collection techniques. Furthermore, using qualitative research methods, like interviews or case studies, could offer profound insights into the viewpoints and experiences of construction experts regarding how BIM influences cost overruns.

In summary, this study advocates that more stakeholder consultation and input is needed to accelerate the use of BIM in construction projects, as it can mitigate the consequences of risk factors related to cost overruns in the construction industry.

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