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BIM Impact on Construction Project Time Using System Dynamics in Saudi Arabia's Construction

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Abstract: Construction delays are a prevalent issue worldwide, and Saudi Arabia is just a short distance from this experience. Although the Saudi construction industry was booming due to Vision 2030, major delays were recorded in numerous construction projects, resulting in extra costs and schedule overruns. Studies on Building Information Modeling (BIM) have increased recently due to their crucial role in managing construction projects. However, more efforts need to be made to define the impact value of adopting BIM using advanced techniques such as System Dynamics (SD). It also aims to demonstrate the BIM impacts globally to encourage taking advantage of such a system. Limited papers studied BIM impact in-depth using advanced techniques such as SD. Thus, A questionnaire was distributed to fifty-nine experts to measure the extent of BIM's influence on the ten factors affecting project delay times discovered in the literature. The statistical analysis results were used to calculate each factor's relative importance index (RII), compare them to the results obtained without BIM use, and calculate the relative difference for each factor. These relative differences were considered in the modified SD. The modified SD was applied to a case study representing an academic building in the King Saud University campus. The main finding revealed that BIM decreased construction project delays by 14.55%. In addition, this study found that BIM has a maximum influence on poor site management and supervision by contractors, with a reduction percentage of 17.65%, and a minimum influence on lack of contractor experience and managerial skills, with 11.76%. The SD analysis results confirmed that BIM has a significant impact on reducing construction project delays.

Keywords: building information modeling (BIM); construction project delays; Saudi Arabia; system dynamics (SD)

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1. Introduction

The construction sector in Saudi Arabia is growing swiftly to meet the increasing demand for projects under Vision 2030. For instance, Saudi Arabia has seen an unparalleled increase in building over the past 20 years, resulting in the fast expansion of the country's infrastructure, including the emergence of new cities, transportation infrastructure, airports, highways, and other types of infrastructure. This expansion, in turn, has led to construction experts worldwide becoming involved in investment and sector development. However, project delay is still a significant challenge hindering the Saudi construction industry. Such a prevalent occurrence of delays, from the point of view of experts and academics, has negatively affected the construction industry [1]. For example, Saudi University Campus construction projects (UCP) experienced delays ranging from 50% to 150%, with 99% overrunning anticipated costs in 2016 [2].

Moreover, in 2019, 40% of Saudi public buildings were delayed [3], and in the following year, 355 reported that educational projects were delayed [4]. Furthermore, the Saudi

Contractors Authority [5] announced that construction firms were the businesses that most frequently claimed bankruptcy. These delays result in various issues, including increasing costs, litigation, conflicts, and project discontinuation. The adverse effects of the delays motivated the researchers to explore the root causes of the delays and the potential solutions. Since 1991, Saudi researchers have narrowed their focus to exploring the factors causing delays and the percentage of delays. Interestingly, within the traditional construction process, the literature revealed consistency in the construction project delay factors between the Saudi context and those of other countries [1].

As a result of the current high delay occurrence, there is a need to use the new technology advantages in the construction industry. Globally, there is an increase in interest in fourth-generation technologies, the most significant of which is Building Information Modeling (BIM) in construction [6]. BIM, a complete process that can improve every aspect of a project, is crucial in the building sector. BIM makes it feasible for design, construction, and engineering teams to employ digital technologies. It typically produces better results overall. In addition, BIM has enormous prospects concerning reducing the scheduled time. BIM boosts technological work during the planning phase by developing 3D models that cover every structural perspective and characterize the framework's requirements competently. Planning assignments may also improve the models [7–9]. Honnappa and Padala [10] utilized BIM in examining delay when considering a change in management.

Notably, even with the wide diffusion of BIM technology and its benefits to project success, there is still a need for project owners, consultants, and contractors to understand how BIM will affect their projects. The lack of trust is one of the biggest obstacles to adopting BIM; the lack of trust extends to methods for project management, communication, and data sharing among team members [11]. Farouk et al. [11] stated that management, readiness, ability, cooperation, cognition, education, and administration establish confidence in BIM-based construction projects. Several studies examined the influences on BIM capabilities, which improved the utilization of BIM. For example, Rajabi et al. [12] investigated crucial factors for evaluating organizational BIM capabilities in Malaysia and Iran. He stated that knowledge of BIM capabilities is needed for the construction industry to recognize the benefits of executing BIM. Rani et al. [13], through an examination of government strategies, discussed the challenges that prevent the use of BIM in the Indonesian construction industry and presented several proposals.

One of BIM's features in improving construction practice is dealing with the Common Data Environment (CDE). Reasonable and operative BIM and Historic Building Information Modeling (HBIM) projects are shared and managed through a CDE. A CDE is a digital medium or software that promotes project stakeholders' cooperation, data sharing, and version control. Within a CDE, various BIM models, data, and documents related to the project are stored, collected, and made accessible to authorized users. This centralized repository ensures all project participants can access the most up-to-date information, reducing errors and enhancing coordination [14,15]. Therefore, sharing data for BIM stimulates its use more in Saudi Arabia.

On the other hand, the interdependencies of the factors that impact the BIM capabilities were examined using a Partial Least Square Structural Equation Model (PLS-SEM) [16] and System Dynamics (SD) [17]. At the same time, Tu et al. [18] evaluated the status of BIM performance in the building phase by studying the interactions among the factors that impact the BIM system using SD. Moreover, most BIM studies have focused on the challenges that hinder BIM performance in such sectors. Moreover, some researchers found that these challenges included delay risk factors that hindered the BIM construction projects, such as ineffective planning and scheduling [19]. This finding, in turn, led to the question: What is the association between the BIM implementation and the construction project delay factors? According to BIM studies, e.g., [10,20–22], it is generally known that BIM implementation contributes to a reduction in construction project delays. Some studies revealed that the delay reduction rate percentages reached savings of 5% to 10% [23]. Nur Sholeh et al. [24] stated that BIM led to a reduction in planning time of 50%, and in some studies, it reached up to 50%. Accordingly, this study intends to raise users' awareness of using BIM by calculating the effect of BIM on Saudi building project delays. Additionally, with limited formal studies investigating BIM impact using advanced techniques like SD, this study seeks to convince industry practitioners to use BIM globally by highlighting its advantages.

The few studies performed either focused on one risk factor, such as ineffective scheduling and planning [19], or the percentage of the influence of BIM on delay factors; this was based on the respondents' perceptions as derived from surveys, such as in [19,25] or interviews, such as in [24] not from a modeling method. Additionally, no studies have attempted to quantify the interdependency of the risk variables linked to building project delays and how utilizing BIM impacts them.

This study intends to assess how BIM adoption affects the risk factors linked to building project delays in the Saudi construction industry. Therefore, several steps are proposed, including the following: (1) a survey of the previous studies to define the most crucial impacts linked to construction project delays; (2) the development of survey questions based on the identified risk factors to be empirically tested among BIM specialists to evaluate the influence of BIM on those risks; (3) the development of an SD model to analyze the BIM influences on such delay factors using actual case study data. This study aims to expand the body of knowledge by determining the degree to which the ten key risk factors linked to project delays in the construction industry were mitigated by using BIM technology. The study aims to improve the performance of construction projects by identifying the decrease in delays brought on by using BIM.

2. Literature Review

Cost overruns and delays are seen as a worldwide issue in the building industry. As indicated in Table 1, several studies have identified elements that affect project delays and cost changes. The Saudi construction market is considered one of the most essential construction markets in the world. The results of these studies show the complexity of the construction market, which is influenced by various factors, including geopolitics, the environment, technology, strategy, and innovation.

Table 1. Studies of delay and cost change.

No.	Reference	Time	Cost	Country
1	[26]	√		Malaysia
2	[27]	√		Malaysia
3	[28]	√		Egypt
4	[29]	√		Qatar, Kuwait, Bahrain, Saudi Arabia, Emirates, and Oman
5	[30]	√		Kuwait
6	[31]	√	√	Saudi Arabia
7	[32]		√	Ghana
8	[33]		√	Denmark
9	[34]	√	√	Saudi Arabia
10	[35]	√		Algeria
11	[36]	√		Morocco
12	[37]	√		Saudi Arabia
13	[38]	√	√	---
14	[39]	√	√	Hong Kong
15	[40]	√		Palestine
16	[41]		√	Korea

2.1. Delay-Related Issues in Saudi Building Projects

The Saudi building sector is expected to experience exponential growth in the coming years as it prepares for the post-oil era when new major cities will be planned and built [31]. Given the importance of the Saudi construction sector since 1991, several local researchers have shed light on improving the sector by narrowing their focus to exploring the causes of delays to create improvement [42–48]. For instance, Assaf and Hejji [45] stated that the average delay ranged between 10% and 30% of the scheduled duration. They pointed out that the most significant delay factor involved change orders. Al-Gahtani et al. [47] utilized the most commonly caused delay factors to forecast the project duration using two techniques (DEMATEL and SD).

Along with the abovementioned studies, Al-Emad et al. conducted a survey study on the Makkah building projects [48]. The research samples included 100 contractors, consultants, and project management firm professionals. The quantitative approach disclosed the top ten factors out of 37 common delay factors in construction projects, including contractor financial issues, insufficient coordination between project parties, lack of labor, delays in producing design documents, inefficient planning and scheduling, expenditure delays, low labor productivity levels, insufficient communication between stakeholders, an inexperienced workforce, and deficiency of contract management.

To examine the main reasons why industrial and manufacturing projects in Saudi Arabia are delayed, Abdellatif and Alshibani [49] conducted a survey study. A thorough literature review revealed 22 delay factors, which were examined by surveying 106 professionals working in the Saudi construction industry. The findings showed that the five leading causes of delays were, in order, complications for the contractor or manufacturer in funding the project, delayed material procurement, slowed material delivery, delayed progress expenses, and delayed approval of design documentation.

Interestingly, it is noted that the elements that contribute to construction building project delays are also present in the Riyadh railway and metro construction projects. For instance, a survey study was conducted by Gopang et al. [50] with 105 participants (i.e., clients, consultants, and contractors) to identify the top five significant delay factors. Across 36 delay factors examined through a review of the literature, the top five delay factors discovered were the decision-making processes by clients and differences in the management processes, layout mistakes, a lack of skilled labor, change orders from clients/consultants, and issues with stakeholder approval and permission, respectively. Similarly, to identify the client-related causes of delays, a survey study was conducted by Alenazi et al. [51] across 37 projects within three key public ministries. Alenazi et al. concluded that there were eight significant causes of delays, including change orders and postponements in their endorsement; poor coordination between the project parties; ineffective time management and planning; lack of finance; varied and defective designs; delays in approving the amended bill of quantities; problems on the job site; and client financial issues. A vital link was found between the delays—variations, design flaws, and payment delays—and the project cost. In examining the problem of delays experienced by building projects and organizations, and vice versa, a work based on a literature review study by Alajmi and Memon [1] noted several delays causes and effects, such as inadequate contract management, incorrect planning, a lack of skilled employees, a delay in decision making, and financial difficulties.

Recently, qualitative research was conducted by Alshihri et al. [31] to investigate and rank the risk factors connected to delays and cost overruns in the Saudi construction sector. Accordingly, 83 risk factors were explored and examined by the questionnaire. The findings revealed that the top ten factors associated with the construction building project delays and cost overruns were the contractor's financial difficulties, the client's uncertainty in making progress expenditures for finished works, contracts being granted to the lowest bidder, change orders throughout the building process; the contractor's inadequate site management and supervision; insufficient contractor experience; delays in the subcontractors' work or by suppliers; and unqualified or inexperienced workers, respectively. The findings have shown problems with the client/contractor relationship and the distribution of tenders, which may allow companies and governmental organizations to develop plans to reduce the risks found in this study. The subject of additional studies might be the force majeure risks and how they affect the relationships between the stakeholders and supply chain systems in the Saudi construction sector.

All the previous studies concluded that the delays in Saudi construction projects were long-standing issues that had created a negative perception of the Saudi construction industry. In addition, it is understood that the Saudi construction industry experience is close to that of developed countries. The paper aimed to examine BIM impact on the top ten project delay factors obtained by Alshihri et al. [31], which examined and ranked the most important risk factors contributing to delays in the traditional processes of Saudi construction projects.

2.2. BIM Impacts on Project Delay

BIM offers features like 3D visualization, clash detection, time and cost estimation, facility management, and synchronization, which provide significant advantages to the construction industry [52]. Several studies, such as [23], have shown that implementing BIM reduces wasted time, project costs, and schedule changes. BIM also positively impacts project time, cost, and quality, leading to quicker decision-making, clash detection, and data loss prevention.

In addition, to determine a link between BIM adoptions and the causes of construction project delays and cost overruns, Muhammad et al. [53] administered a survey study to 69 contractors in the Malaysian construction sector. The results demonstrated a relationship between the causes of delays and cost overruns. However, this study did not address the risk factors contributing to construction project delays and cost overruns. The findings also revealed a negative relationship between BIM adoption and the causes of delays and cost overruns. The study suggested that the increasing usage of BIM led to a substantial reduction in the cost and duration of construction projects. This finding is consistent with studies such as that of Egwim et al. [21], who conducted a systematic review, confirming the positive impact of BIM on construction project delays.

Similarly, survey research by Sarvari et al. [25] sought to identify and investigate factors that might impact the duration, cost, and quality of mass housing construction projects. The data analysis of 50 respondents from the construction industry showed a high cost and time reduction in the construction phase compared to the pre-construction phase, with a higher reduction in time and cost in the post-construction phase. In line with the residential development sector, there was an attempt to investigate the effects of BIM on the construction of two-story homes in Jeddah city. Thus, quantitative research was carried out by Almujibah [22] to look at the success factors for time and money savings in construction projects. Consequently, the results showed that BIM considerably improved home construction projects' cost, time, quality, safety, efficiency, and environmental impact.

Alongside the studies mentioned above, there is an attempt to improve the performance of BIM abilities in managing construction delays. For example, Ali et al. [54] study claimed that BIM technology could not deal with construction delays due to a lack of associated features in such technology. As a result, a prototype called BIM-based Construction Delays Recorder (BIM-CDR) is developed for storing and visualizing information related to construction delays. Several BIM-CDR prototype benefits were identified, such as delay management, easy-to-identify delay locations, visualization of the delay's impact, managing contracts, resolving disputes, and lessons learned. Furthermore, the same study suggested that several potential challenges linked with the implementation of BIM-CDR are, namely, a lack of BIM expertise, financial and educational needs, resistance to change, and legal constraints [54].

Regarding the impact of BIM in causes delay factors, such as inadequate planning and scheduling, in this context, construction planning and scheduling include sequencing activities over time and space considering procurement, the resources available, spatial constraints, and other process elements [55]. For example, a quantitative analysis was carried out by Nawaz et al. [19] to examine how BIM affected project planning and scheduling. The survey indicated a connection between efficient project planning, scheduling, and BIM usage.

The traditional scheduling techniques are limited in terms of detailed plans and cannot deal with strategic issues such as BIM. In addition, BIM can be applied to accelerate the project schedule, and it is not easy to demonstrate that impact with traditional scheduling techniques. This BIM impact requires a more holistic approach to quantifying, such as SD [56]. It is necessary to comprehend the strategic problems of the BIM impact to reduce project delays; this can only be accomplished through a more standard systematic analysis such as SD.

2.3. System Dynamics

SD is a computer-aided methodology for formulating strategies and policies. The fundamental objective is to assist researchers in making better decisions when challenged with complexity. Many fields of research and engineering have used SD in various ways. SD can be used to consider the correlations between system factors and their variance with simulation time. Al-Gahtani et al. [47] developed an SD model that assumed design and implementation errors during construction. The model considered the most time-delaying factors identified by Alshihri et al. [31] and their interdependencies with the project delay. This model was considered in this paper after performing modifications, as illustrated in the methodology section, to measure the impact of BIM on the most time-delaying factors and the project end time.

2.4. Research Gap

As previously indicated, most of the BIM research concentrated on investigating the factors contributing to delays in construction projects. However, few studies assess how BIM affects particular delay causes, such as inefficient planning and scheduling [19]. Some studies relied on professional opinions, but none offered any concrete proof that quantified the extent to which BIM impacted the project delays. For this reason, this study fills this gap using the SD modeling technique.

3. Methodology

The paper's aim of determining BIM time impact on projects was assessed by integrating the experts' judgments into the developed SD using statistical analysis. Therefore, the research design method followed in the study combines a survey and an analytical study. The methodology consists of five steps: design and execute the questionnaire; analyze the questionnaire data; compute the BIM reduction degree based on the relative importance index; integrate the reduction factors into the SD developed by Al-Gahtani et al. [47]; and compute the BIM influence on the delay factors that affect project time. The steps are shown in Figure 1.

3.1. Design and Implement a Questionnaire

Survey Study

The survey study aims to investigate BIM's importance on project delay factors. Accordingly, this study relied on the Alshihri et al. results. Alshihri et al. [31] gave a questionnaire to 55 experts and ranked Saudi construction projects' most crucial project delay factors using statistical analysis. The study findings concluded the top ten factors as contractor's financial difficulties (F1), payment delays by owners for completed works (F2), contract awarded to the lowest bidder (F3), change orders during the construction phase (F4), ineffective scheduling and planning by the contractor (F5), shortage of manpower (F6), poor site management and supervision by contractors (F7), lack of contractor experience and managerial skills (F8), delays in subcontractors' work or by suppliers (F9), unqualified/inexperienced labors (F10) [31]. The top ten factors were identified and formulated in a survey study. Therefore, the questionnaire design and testing process involved several steps. In the first step, a questionnaire question list was formulated from the literature review, i.e., [31]. As a result, 10 top delay risk factors have been determined and constructed in the first draft. In the second step, five semi-structured in-person interviews were conducted with BIM specialists in the Saudi construction industry with at least eight to ten years of experience to ensure respondents understood the questions. This process was crucial to revising, confirming the risk factors, and further structuring relevant components. Some risk factors were therefore excluded. A pilot study was conducted via a web-based questionnaire in the third step.

As a result, 26 various BIM specialists responded to rate the potential influence of BIM on risk factors related to project delay. The five-point Likert scale, very high effect (very high), high effect (high), medium effect (average), little effect (low), or no effect, was used as shown in Table 2. In the fourth step, as a result of the preceding step, the main study was a web-based questionnaire. Only 59 BIM specialists had completed the survey. Despite efforts to increase responses by re-emailing pertinent companies, no additional responses were eventually obtained. This issue results from the shortage of BIM experts in the Saudi construction industry. The demographic information of the 59 experts in the fourth step is shown in Table 3. All the experts had experience implementing BIM techniques in construction projects, as shown in Table 3.

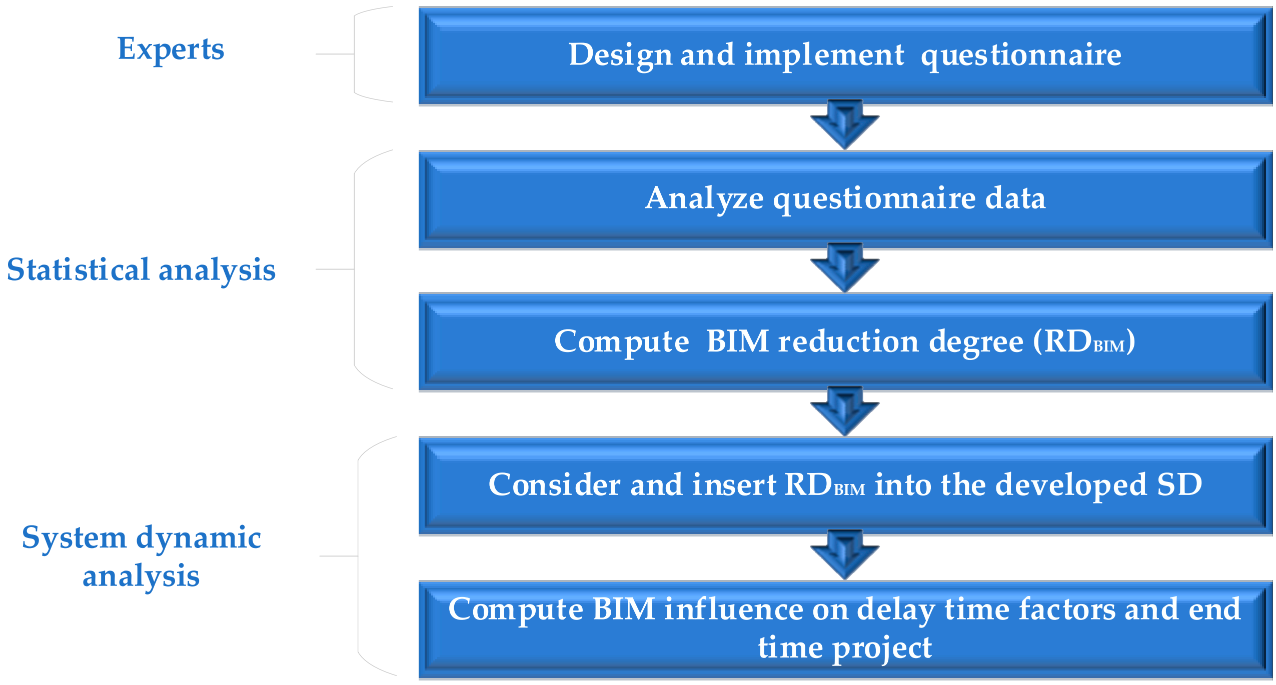

Figure 1. Flowchart methodology.

Table 2. Five-point Likert scale and estimated balance.

Likert Scale	Responses
1	Very low
2	Low
3	Medium
4	High
5	Very high

Table 3. The demographic information of the questionnaire participants (experts).

Section	Item	Response	Descriptive Analysis
Firm Information	Firm activities	Contracting Company	23.21
		Firm for Project Management and Consulting	51.79
		Maintenance and Operation Company—OM	0.00
		Construction and Operation Company (OP)	8.93
		Other	16.07
	Firm sector	Private sector	64.29
		Public	30.36
		Other	5.36
	Role of firms in construction	Owner	19.64
		Project Manager	26.79
		Design Consultant	21.43
		Supervision Consultant	12.50
		Contractor	19.64
Personal Information	Construction project position	Construction Manager	9.30
		Site Engineer	4.65
		Technical Manager	9.30
		Technical Office Engineer	11.63
		BIM Manager	25.58
		BIM Specialist	6.98
		BIM Coordinator	9.30
		Quality Control Engineer	6.98
		Project Control Engineer	0.00
		Planner	2.33
		Quantity Surveyor	0.00
		Contracts Manager	6.98
		Other	6.98
	Experience years	1–5	51.79
		6–10	17.86
		10–15	17.86
		+15 years	12.50

3.2. Analyze Questionnaire Data

The questionnaire includes general information and delay risk. The code of the descriptive data was performed and converted into digitalized data. The missing data were processed and replaced by the mean value, especially in the second part of the questionnaire. Then, the data were statistically analyzed based on the respondents' demographics. The data reliability was evaluated by measuring Cronbach's alpha, which was determined using Equation (1).

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

s_i^2 is the variance of factor i, s_t^2 is the variance associated with the observed factors of a specified group, and M is the total factors in a specific group. The relative importance index (RII) of the delay factors with BIM considered can be computed based on the frequency of the five-point Likert scale and using Equation (2):

$$RII_{with\ BIM} = \frac{\sum_1^5 W.f}{A \times n} \times 100 = \frac{f1 + 2 \times f2 + 3 \times f3 + 4 \times f4 + 5 \times f5}{5 \times n} \times 100 \quad (2)$$

where W is the weight of the importance level (1 to 5) corresponding to the impact scales for the Likert scale. f1–f5 represents the corresponding frequency for each point of the Likert scale. A is the highest point of the five-point Likert ordinal scale, which was 5 in this paper, and n is the total frequencies or the total responses of each variable.

3.3. Compute BIM Reduction Degree (RD_{BIM})

Alshihri et al. [31] computed the RII of the project delay factor without considering the BIM influence. These RII values were considered in this paper as $RII_{without\ BIM}$. Therefore, the RD_{BIM} was computed depending on the $RII_{with\ BIM}$ and $RII_{without\ BIM}$, as shown in Equation (3). Therefore, each delay factor (F_i) had RD_{BIM-i}.

$$RD_{BIM-i} = \frac{RII_{without\ BIM-i} - RII_{with\ BIM-i}}{RII_{without\ BIM-i}} \quad (3)$$

3.4. Consider and Insert RD_{BIM} into the Developed SD

An SD model consists of flows, stocks, and dynamic variables; these components were arranged in specific patterns connected by links, as shown in Figure 2. The flow in an SD is the rate of change in the reservoir associated with that flow. Therefore, the unit of flow is the unit of the stock over a time unit. The SD model developed by Al-Gahtani et al. [47] considers two error types (design error and construction work error), which mainly influence the progress rate of the project. In addition, the ten project delay impacts were modeled as ten dynamic variables in the SD model, and they influenced the design error and construction work error loops. In addition, the model consisted of four stocks and five flows. The equations of the five flows are shown in Table 4 [47]. Concerning the relationships among the ten factors, Al-Gahtani et al. [47] established the causal loop and the relationship among them using DEMATEL techniques, integrated them into the stock and flow diagram, and developed the SD model.

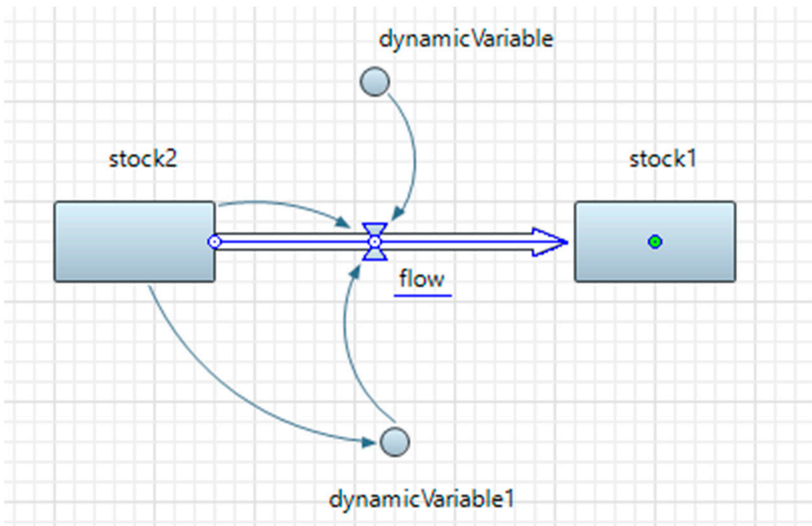

Figure 2. An illustrative example of a component of the SD model.

Table 4. Five flow equations of the SFD model [47].

Name of Flow	Flow	Formula
Progress rate	Flow 1	$TIME_1 - (Flow_2 - Flow_3 + Flow_4 - Flow_5) \times (F_1 + F_2 + F_3 + 0.111F_9 + 0.111F_6 + 0.125F_7)$
Detected redesign rate	Flow 2	$Flow_2 = TIME_2 \times (1 + 0.25F_5 + 0.111F_6 + 0.125F_7)$
Redesign tasks rate	Flow 3	$Flow_3 = TIME_3 \times (1 - 0.25F_5 - 0.111F_6 - 0.166F_{10} - 0.166F_8)$
Detected rework rate	Flow 4	$Flow_4 = TIME_4 \times (1 + 0.111 + 0.125F_7 + 0.166F_8 + 0.166F_{10})$
Rework tasks rate	Flow 5	$Flow_5 = TIME_5 \times (1 - 0.25F_4 - 0.111F_6 - 0.125F_7 - 0.166F_8 - 0.111F_9 - 0.166F_{10})$

In this paper, the SD model developed by Al-Gahtani et al. [47] was considered because the model considered the top ten project delay factors in Saudi Arabia, the same as the ten factors in this study. The structure model that was developed by Al-Gahtani was modified by creating ten dynamic variables, which were named BIM1-BIM10. Each dynamic variable was connected to the corresponding project delay factors (F_i). For instance, the dynamic variable of BIM1 was linked to the project delay factor (F1). It should be noted that the dynamic variables also represented the project delay factors [47]. Because the ten dynamic variables were created, the developed SD model's structure was changed, and the model was named the modified SD model. The values of the dynamic variables (BIM1-BIM10) were (RD_{BIM-1}–RD_{BIM-10}), respectively. The weight equation of the project delay factor was changed, as given in Equation (4).

$$WF_i = Maximum\left[(1 - RD_{BIM-i}/100) \times WF_i^{Initial}, \sum_{j=1}^{n_k} \frac{WF_j}{n_j}\right] \quad (4)$$

where i is the i^{th} factor, n_k is the total number of project delay factors that have influenced the i^{th} factor, and WF_j represents the weight factor of the j^{th} factor that influenced the i^{th} project delay factor. n_j is the number of influences of the j^{th} project delay factor. Figure 3 shows a simple sketch that considers the effect of BIM_i on the developed SD.

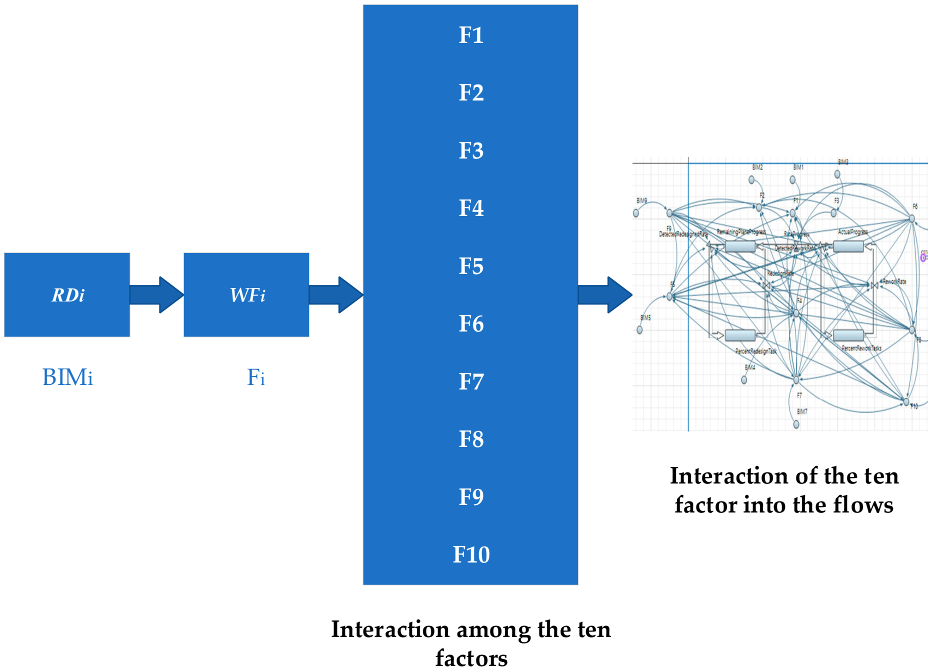

Figure 3. Sketch considering the process of BIM in the developed SD.

3.5. Compute BIM Influence on Project Delay Factors and Project End-Time

After creating dynamic variables of the BIM and considering their RD_{BIM} in the project delay factors formula, the modified SD was run. The model outputs forecasted the progress with the time and the weight of the project delay factors, which were changed through the analysis.

The progress with time represented one of the outputs of the model. The model's time was the original contract time. In other words, the progress at the end of the original contract time was less than 100%. The progress–time curve was then fitted using the S-curve in the Excel software (version 2019) to predict the contract end time (project delay plus original contract time). Then, the fitted curve was extended to 100% progress. Three primary components are typical of an S-curve [57]. The early or dormant stage contributes 10%. The ramp stage (80% of the growth) is followed by the saturation stage (10%). The time of the median of the third part (progress at 95%) was considered the contract end time.

The weight of the project delay factor with the BIM influence, which was changed based on the interaction among the factors, was considered. The weight values were then compared with the corresponding weight without the BIM influence to determine the percentage of BIM influence when considering the interactions among the project delay factors.

4. Results

Effect of BIM on the Project Delay Factors

Based on the statistical analysis of the questionnaire data, Figure 4 displays the RII of the ten project delay factors with/without the BIM influence and RD_{BIM}. The horizontal axis is the project delay factor, and the ordinate axis is the RII with/without BIM influence. In general, BIM decreased the RII of the project delay factors, except in F6, which was represented as a shortage in manpower. Figure 5 displays the RD_{BIM} for each factor. The experts' opinions stated that there was no BIM influence on the shortage of manpower. Therefore, the RII with the BIM and RD_{BIM} of F6 was omitted. The BIM had a maximum influence on F2 (payment delays by owners for completed works), with an RD_{BIM} of 25.34%, and it had a minimum with F8 (lack of contractor experience and managerial skills), with an RD_{BIM} of 12.17%.

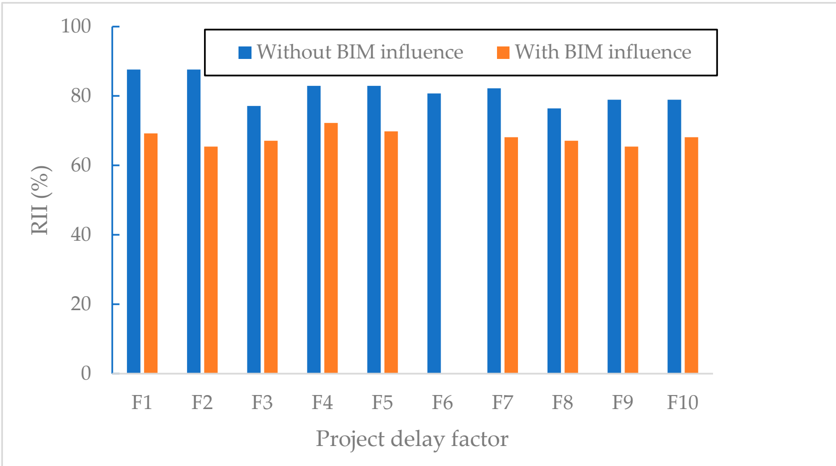

Figure 4. RII of the ten factors with and without BIM influence.

On the other hand, the RII results shown in Figure 4 did not consider the interactions among the project delay factors. First, the ten RD_{BIM}s were inserted into the modified SD model to overcome the issue, and the interactions were captured. Then, the outputs provided the weight values of the ten project delay factors after running the modified SD model, as shown in Figure 6, which shows the structure of the modified SD model. It also shows the weight value of the ten project delay factors beside the project delay factor labels. In addition, the SD model developed by Al-Gahtani et al. [47] was utilized to estimate the weight values of the ten project delay factors without the BIM influence. The structure with the values of the model is shown in Figure 7. The reduction in BIM impact can be calculated as the weight difference between using and not using BIM divided by the weight value without BIM for each project delay factor. Table 5 shows the weights of the ten- project delay factors without/with BIM influence and the reduction in the BIM impact. The weights of the factors with the BIM influence were generally smaller than those without, with an average reduction in the BIM impact of 14.47%. The project delay factor with the maximum BIM influence was F7 (poor site management and supervision by contractors), with a reduced BIM impact of 17.56. However, the RII method provided F2 as the maximum factor that had a BIM influence. On the other hand, the minimum reduction in the BIM impact was caused by F8 (lack of contractor experience and managerial skills), with a value of 11.67%. This reduction agreed with the RII method.

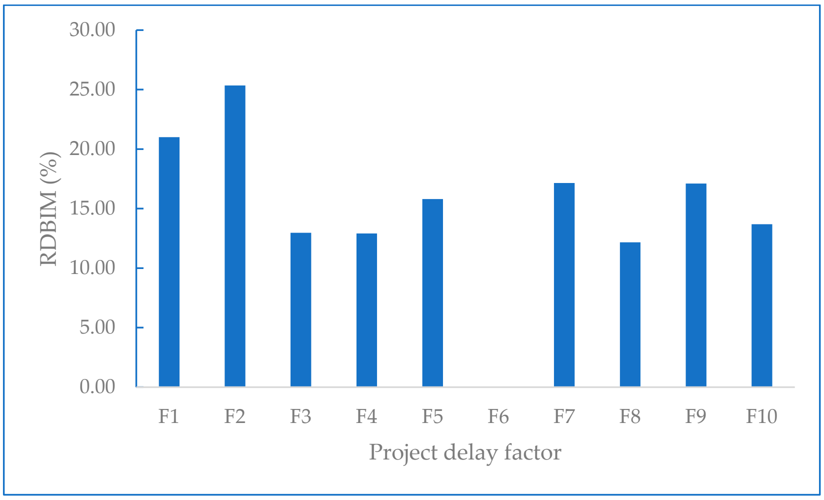

Figure 5. RD_{BIM} of the ten delay factors.

Table 5. Weight of the project delay factors without/with BIM.

Factor	Symbol	without BIM	with BIM	Reduction in BIM Impact (%)
Contractor's financial difficulties	F1	0.120	0.104	13.33
Payment delays by owners for completed works	F2	0.097	0.083	14.43
Contract awarded to the lowest bidder	F3	0.090	0.078	13.33
Change orders during the construction phase	F4	0.095	0.083	12.63
Ineffective scheduling and planning by the contractor	F5	0.110	0.092	16.36
Shortage of manpower	F6	0.097	0.097	0.00
Poor site management and supervision by contractors	F7	0.102	0.084	17.65
Lack of contractor experience and managerial skills	F8	0.102	0.09	11.76
Delays in subcontractors' work or by suppliers	F9	0.101	0.084	16.83
Unqualified/inexperienced labors	F10	0.101	0.087	13.86

Regarding the reduction in project delay, the modified SD model was applied to the case study, and the actual progress curve and the fitted progress curve, which the modified SD model computed, were compared to determine the reduction in project delay. The general information of the case study, which represents the academic building on the King Saud University (KSU) campus in Riyadh with a total built-up area of more than 14,500 m2, is summarized in Table 6. The actual duration of the case study was 48 months, more than two times the scheduled duration (24 months). Several causalities of project delays were analyzed through discussions with key personnel, including the residential building's construction manager, project leader, and site engineer. Project documents, in terms of accomplishment reports, were also investigated. The case study was an academic building with a total area of 14,865 m^2. The type of building was structural precast concrete with concrete footings. The selected case study suffered from ten- project delay factors, particularly the change orders factor. This delay is caused by inaccurate or incomplete project drawings, in which the BIM has a significantly positive influence in reducing these factors' impact and, eventually, the project's performance. Therefore, the ten-project factors (F1–F10) with their corresponding RD_{BIM} were inserted into the modified SD model, and the model was run. Figure 8 shows the actual and forecasted progress when considering the BIM impact. The forecasted end time was 39 months, shorter than the actual end time (48 months). The percent reduction in project delay was computed using Equation (5), and it was 14.55%, which was very close to the average of the reduction in the BIM impact (14.47%).

$$\%\ Reduce\ in\ time\ delay = \frac{(Actual\ end\ time - Forecast\ end\ time)}{Actual\ end\ time} \times 100 \quad (5)$$

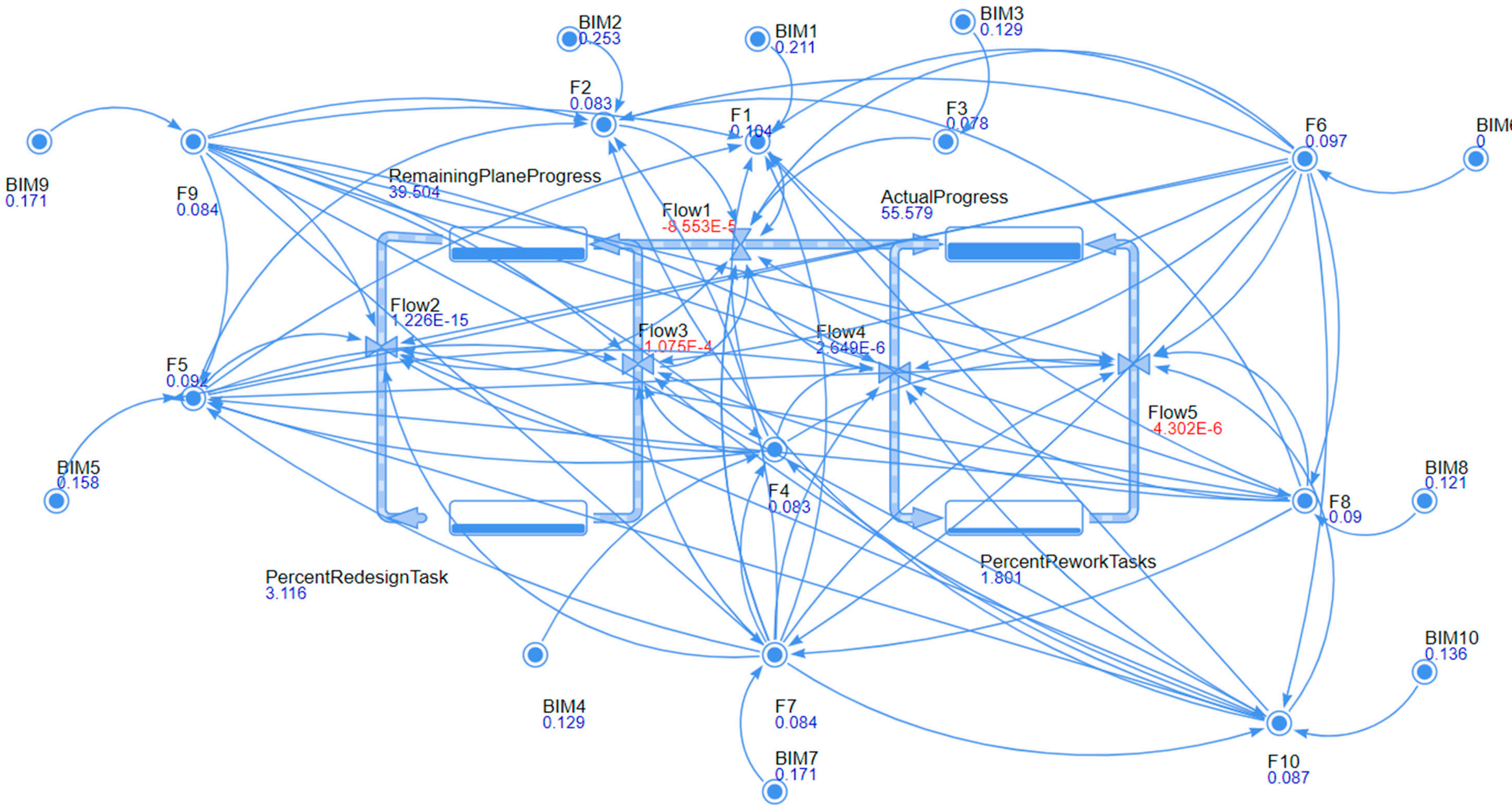

Figure 6. Output of the modified SD model (with BIM influence).

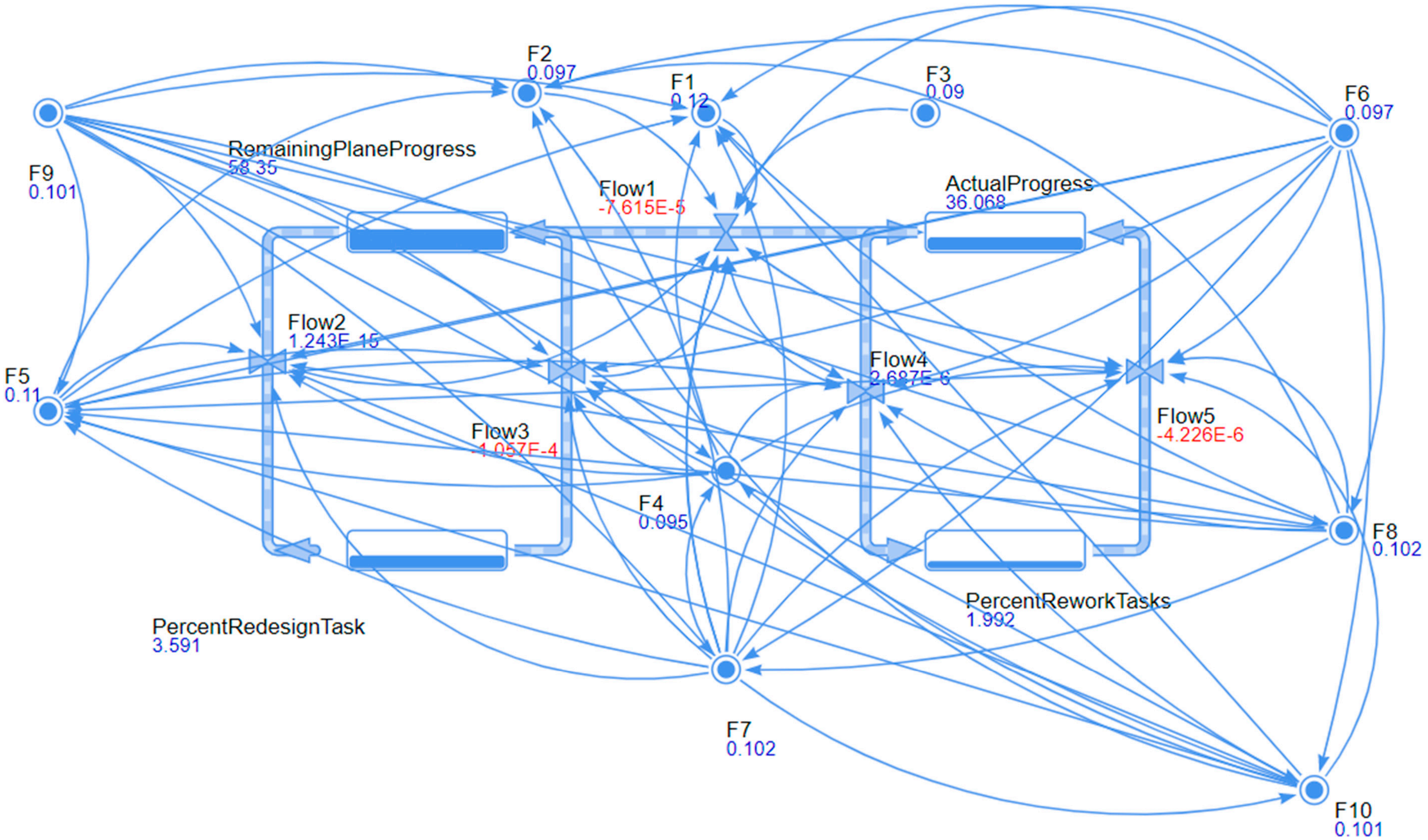

Figure 7. Output of the SD model (without BIM influence) [47].

Table 6. The case study information.

Item		Description
Project type		Academic building
Total area of the building		14,865 m^2
Structural type		Precast concast concrete
Region		Riyadh, King Saud University campus
Designed schedule	Start date	February 2015
	End date	February 2017
Actual schedule	Start date	February 2015
	End date	January 2019

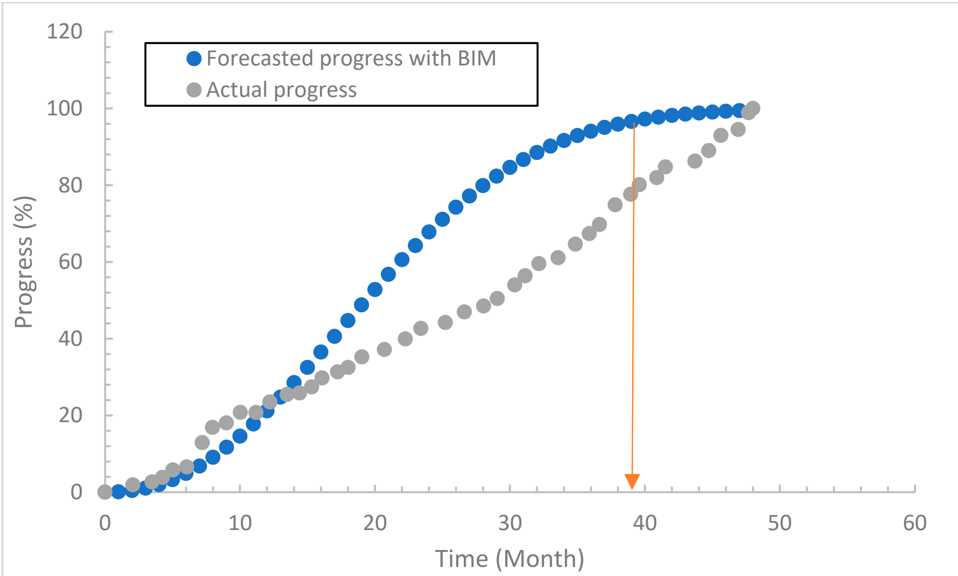

Figure 8. Forecast and actual progress of the first case study.

As a result, the BIM impact prediction of thirty-nine months generated by the SD model was difficult to determine using the current traditional scheduling techniques. Usually, a project is goal-oriented, open, and generated by a human system exposed to uncertainty and instability. The disruptive impact of subjective human variables has increased due to the complexity of the projects and their environments. One of the soft aspects that affect project complexity is BIM. Current scheduling techniques need to be enhanced when dealing with such project complexity. SD is one of the simulation methodologies that can measure the BIM influence on a schedule compared to conventional scheduling techniques [56].

Notably, the modified model can be used in countries with comparable project settings by applying one of the two methods. The first method represents taking the percentage project delay as a comparison value between other countries and Saudi Arabia. The second method represents taking the same methodology in different countries. Additionally, decision-makers may find the modified model and its findings helpful in promoting BIM adoption in the construction industry.

5. Discussion

On-time delivery remains a major challenge threatening the construction project sector due to its adverse impacts on increasing project costs. This paper aimed to measure the BIM impact that could affect Saudi construction building project delays. Quantitative research was applied using surveyed questionnaires collected from 59 project participants involved in BIM construction projects. These factors were ranked based on their RII index and examined in the SD model.

The key findings demonstrated a relationship between the usage of BIM and the decline in construction building project delays. This result aligns with other studies worldwide, such as in Indonesia's construction industry and the industries of India, the UK, and others. This research showed that the average reduction in project delays caused by BIM use compared to projects without BIM was 14.47%. This result is consistent with previous studies on reducing project delays by 5 to 10% [23] and 50% [24]. The findings also showed that the delay factor with the maximum BIM influence was poor site management and supervision by contractors (F7), as shown in Table 5. The work of subcontractors or suppliers (F9) and ineffective scheduling and planning by the contractor (F5) are the second and third largest project delay factors affected by BIM, respectively. As shown in Table 5, BIM can reduce these factors by 16.83% and 16.36%, respectively. However, the minimum reduction rate of the BIM impact of 11.67% was due to the lack of contractor experience and managerial skills.

Regarding poor site management and supervision by contractors (F7), the study demonstrated that BIM reduced the delay factor impact by 17.56%. This reduction is because the BIM improved the contractor's leadership skills by enhancing the exchange and sharing of information among the project parties. This enhancement improved the contractor's ability to communicate and coordinate visually among the stakeholders. Additionally, it supports contractors in managing site logistics and monitoring construction progress [57]. Moreover, the significant features of BIM were the digitalizing and visualizing of the project data in 3D, the detection of clashes, and the synchronizing of the changes instantly among project parties. These features, in turn, improved contractor performance in managing and supervising projects.

Regarding delays in subcontractors' work or suppliers (F9), the results showed that BIM reduced the impact of the delay factor by 16.83%. This reduction is attributed to BIM enhancing understanding of the construction task sequence and the project timeline [55], identifying the accurate bill of quantities required to construct a project and the time needed, enhancing synchronization of the procurement process with the design and construction phases [55], noticing clashes in advance and addressing them before they become severe issues on the site, facilitating communication processes between suppliers and subcontractors, and estimating accurately the amount of materials required from suppliers based on the project planning and scheduling. In light of all the above features, BIM's usage simplified the contractor's collaboration with suppliers and subcontractors.

Regarding risk factors of ineffective scheduling and planning by the contractor (F5), the findings indicated that BIM reduced the delay influence by 16.36%. As it was ranked as the fifth delay factor in the Saudi construction project time [31], the reduction that BIM made on such construction planning and scheduling is considered a positive sign of the influential role of BIM in reducing the impact of such factors on Saudi construction project time. This reduction is due to the 4D and 5D BIM advantages linked with the project data. For this reason, our results align with the body of research showing that BIM positively impacts construction project planning and scheduling [19]. BIM adoption has fundamentally changed the planning and scheduling process in the construction industry since it can link project information with the planning stage [19]. Previous studies have demonstrated that BIM adoption has provided a practice with several advantages. For example, the Common Data Environment (CDE) provides a secure platform for sharing BIM data, models, and documentation across the project group. It ensures all group members operate with precise and consistent data [58]. The CDE stimulates data exchange between different software applications used in the BIM workflow. It sustains interoperability and information integration, allowing seamless contact between tools and systems.

Open-source BIM projects can play an essential role in facilitating the adoption of BIM [59]. Therefore, this technique may encourage BIM adoption in Saudi Arabia's construction industry. Moreover, open-source BIM projects guide BIM software or platforms that are freely available and permit users to access, change, and spread the source code [60]. Open-source BIM software minimizes the need for expensive proprietary software licenses. This makes it more accessible and affordable for construction companies, especially smaller organizations, or those with finite budgets, to adopt BIM technology. In addition, open-source BIM projects provide the flexibility to customize and tailor the software according to specific industry requirements and local standards in Saudi Arabia. This flexibility allows for developing BIM tools that align with the country's construction practices and regulations.

Contrary to expectations, the implementation of BIM did not have the maximum effect on the change order factor since one significant risk factor resulted in delays documented in the literature.

In terms of the contribution to knowledge, this study is the first attempt in the BIM literature to investigate the BIM impact on construction project delays by focusing on the top ten risk factors, with their interdependencies connected to project delays and cost overruns, not just delay causes. The delayed projects led to additional costs. Therefore, this paper contributes to clarifying the difference in the delay between BIM and non-BIM projects, enabling projects to be measured using the SD system.

Concerning the implications for the practices, including those of contractors and government authorizers, a clear conclusion was drawn from this study: BIM technology is the most proper construction management approach to level up the construction industry. In addition, such a study also provided an in-depth understanding of the benefits and challenges of BIM technology during the construction phase.

6. Limitations and Recommendations

Despite the achievement of the research aim, this study has some limitations. First, this study might be interpreted in the context of the BIM maturity level of the Saudi construction industry. Still, the interpretation might differ in other countries, especially developed ones. Secondly, the research data only focused on exploring the impact of BIM use on construction project delays. Further research could be undertaken to explore the effect of BIM on construction projects' cost overruns. Finally, to generalize the study results, further case studies and experimental studies should examine larger sample sizes of professionals in different countries with various project types and sizes. Additional investigation is recommended to benefit the Saudi construction industry, and lessons should be learned from other BIM markets to establish the best BIM implementation strategies for the Saudi construction industry.

7. Conclusions

The importance of BIM studies in managing construction projects has recently increased. However, more work needs to be conducted to explain how using BIM affects building project delays. This study intended to assess how using BIM affects the risk factors for project delays in the Saudi construction industry. After a literature review, the methodology consisted of five steps to achieve the purpose. The first step was to design and implement the questionnaire to measure the degree of BIM impact on the top ten project-delay factors. Then, the questionnaire data were statistically analyzed to compute RII for each project delay factor with and without BIM influence. After that, the RDBIM values were computed based on the RII values. The RDBIM values were inserted into the modified SD model. The modified SD model was applied to the case study, and it determined the reduced project delay. The main findings revealed that BIM has a maximum and minimum impact on the project delay factors "poor site management and supervision by contractors, F7" and "payment delays by owners for completed works, F2", with reduction percentages of 17.65% and 11.76%, respectively. In addition, BIM does not influence "Shortage of manpower, F6". The percent reduction in project delay was 14.55%.

Moreover, BIM improved the performance of the construction task sequence and project timeline. Hence, BIM usage reduced the impact of the delay factor of "Delays in subcontractors' work or by suppliers F9" by 16.83%. The relative weight of the delay factor of "ineffective scheduling and planning by the contractor, F5" was decreased by

16.36% because of using BIM in construction. The outcomes assist the decision-makers in comprehending the benefits of BIM adoption in the Saudi construction sector. The adoption of BIM in the construction industry may be accelerated with more research and using the lessons of the industrialized nations.

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Abbreviations

Symbol	Description
BIM	Building information modeling
UCP	University campus project
RFI	Request for information
BIM-CDR	BIM-based Construction Delays Recorder
SD	System dynamics
s_i^2	Variance of factor i
s_t^2	Variance associated with the observed factors
M	Total factors in a specific group.
W	Weight of importance level (1 to 5)
n	Total frequencies. The total responses of each variable
$RII_{without\ BIM}$	RII of the project delay factor without considering the BIM influence.
$RII_{with\ BIM}$	RII of the project delay factor with considering the BIM influence.
RD_{BIM-i}	Relative difference due to BIM is a function on $RII_{without\ BIM}$ and $RII_{with\ BIM}$
WF	Weight factor of the j^{th} factor
n_j	Number of influences of the j^{th} project delay factor

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