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INVESTIGATING THE ROLE OF BUILDING INFORMATION MODELING IN RISK MANAGEMENT OF CONSTRUCTION PROJECTS

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Abstract — Risk management is a crucial component of building projects that aids in achieving objectives and reducing risks. Risks associated with management, such as coordinating between disciplines and communicating with stakeholders at various project phases, are common in construction projects. This study set out to get a deeper understanding of the ways in which risk management planning methods for building projects might be developed using Building Information Modeling (BIM). A survey instrument was created and dispersed among specialists in the building sector. The questionnaire's results showed that, despite certain challenges like inadequate training and improper utilization in construction contracts, building information modeling is useful in risk management planning procedures. These challenges could make it impossible for building information modeling to be used in building projects. The majority of respondents did, however, agree that BIM is a useful tool for managing project risk in construction. The study concludes with a conceptual framework for using BIM in risk management procedures across several project life cycles.

***Keywords*:** risk management planning, construction project, Building Information Modeling (BIM), construction, coordination, stakeholder

1.0 INTRODUCTION

Achieving the project objectives—time, money, quality, scope alignment, and customer satisfaction—is the primary goal of project management for construction projects. Numerous dangers pose a threat to the project at various points throughout its life cycle. Reducing the detrimental impact of any risks on the project deliverables is the essence of efficient project management. There are several ways to categorize project risks, and one of them is management-related risk, which includes things like the variety of stakeholders in the building project and the need for coordination across various disciplines like plumbing, mechanical, electrical, and architectural. In order to meet project deliverables, coordination is essential. The National BIM Standard defines Building Information Modeling (BI)M as "a digital representation of physical and functional characteristics of a facility," as well as a "shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle"; as existing from earliest conception to demolition [1–4].

The building information model includes a large quantity of project data. Because the model can define and describe the geometry, spatial relationship, geographic information, quantities and properties of building elements, cost estimates, material specifications, and project schedule along the project life cycle, it is now easier to extract necessary information, such as material quantities and specifications, relationships between various disciplines, sequences, scope of work, and any documents like drawings, procurement details, submittals, and any related information [5–9]. The use of BIM in a project has many advantages, including the ability to quickly identify conflicts, provide precise drawings, facilitate model-driven fabrication, assist lean construction methods, provide construction planning and scheduling, and manage project budgets. While studies examining the advantages of utilizing BIM are limited in scope and rarely offer quantitative numbers, they provide a comprehensive list of benefits and associated expenses [10].

2.0 PROBLEM DEFINITION

There are many common objectives in construction projects, such as completing the work on schedule and staying within the budget allotted, yet there is a glaring absence of effective coordination across the numerous disciplines involved in the project. Moreover, many problems may be encountered in large construction projects, which makes it necessary to increase the efficiency of communication between the project parties, including contractors, designers, and suppliers, in order to maintain appropriate information exchange between the various parties [11–15]. Most contracting companies try to maintain traditional methods of work, whether in the fields of design, execution, or management. The traditional ways of confronting project risks increase the chances of these risks occurring and also require a lot of effort and resources to try to avoid them. On the other hand, the use of modern tools in risk management may be more effective in avoiding the risks facing the project, especially those related to coordination between the various areas of the project and coordination between the project parties in the handling of project information [16, 17].

Plans, designs, and specifications for project items and components are developed during the design stage of the project life cycle, which is regarded as one of the crucial and significant stages. Businesses that create plans using conventional techniques, such as CAD software, may find that there is a glaring lack of coordination across the project's many disciplines. Additionally, creating the coordination plans needed to complete the work is labor-intensive and time-consuming. On the other hand, exchanging the most recent revisions of the plans presents a challenge as well as the potential for delays or discoordination [18–22].

3.0 GAPS IN THE LITERATURE

After reviewing the previous research, it was found that most of the previous studies focuses on analyzing the risks and identifying the traditional tools to avoid these risks, for example, but not limited to meetings, and these tools may require a lot of time and effort that affects the project duration. There is a lack of research that focuses on the use of BIM technology as a key tool in project risk management. A number of studies have demonstrated the value of building information modeling technology in the construction industry and its ability to positively impact projects. However, there have been some gaps in the literature regarding the application of BIM as a tool for risk management in project management, which have been addressed in this study. The main goal of the study is to ascertain how using BIM affected risk management, particularly during the project's design and construction phases.

3.1. Study Motivation

This research aims to look closely at the role that information technology plays and how it affects risk management in construction projects. It would also be of interest to explore optimal strategies for applying building information modeling to projects, particularly within the framework of a BIM execution plan (BXP). A company will be overwhelmed by the outcomes once it begins using BIM in the project; according to Zeiger [23], "firms that have switched to BIM don't switch back" to 2-D. To facilitate model approval by contractors and architects, many jurisdictions actively promote BIM plan checking procedures formalized as "BIM Execution Plans" or "BXP." [24–28].

3.2. Aims and Objectives

The use of modern technology in project management is one of the factors that influence raising performance, reducing risk, and providing quick access to the project's objectives. Therefore, the aim of this research is to study the effect of using BIM to manage risks, and thus, the following objectives are formulated: Firstly, identifying project risks due to the multiplicity of stakeholders, coordination between the different AEC disciplines that are involved in the project life cycle, from design to planning and ending with execution phases, and the probability of their occurrence in both organizations that apply Building Information Modeling (BIM) and organizations that do not apply this technique. The sequence and likelihood of these risks on the main objectives of the project (the project's duration and budget) in both the organizations that apply (BIM) and others that do not.

3.3. Significance and Advantages of the Study

Using BIM can provide a cooperative sharing and exchange information forum for different parties and disciplines and can improve project management along the facility lifecycle by providing an interactive environment for the project. Using CAD technology in the AEC industry facilitates the process of communication in construction projects [29–31].

The significance of this research is to exploit the proper utilization of information technology, which can mitigate or avoid these risks by solving coordination problems and lack of communication between different project parties. The aim of the research is to investigate the role of building information modeling as an effective tool that can be used to mitigate these risks and reduce negative impacts on project deliverables. BIM is now used in a vast range of applications and is no longer just for information exchange or clash detection. Six essential features of a good BIM application are: inclusive (building performance, constructability, project schedule, etc.); measurable (with quantifiable and query-able data); durable (reflecting as-built conditions throughout a building's lifecycle); available (allowing information sharing to the entire project team through an interoperable platform); numerical (capacity to simulate design and construction phases); and 3-D (3D representation of complex construction conditions) [32, 33].

4.0 RESEARCH METHODOLOGY

The research methodology consists of six sequent phases' starts with data gathering of literature review and ends with conclusion and recommendations. Figure 1 represents research methodology as shown below.

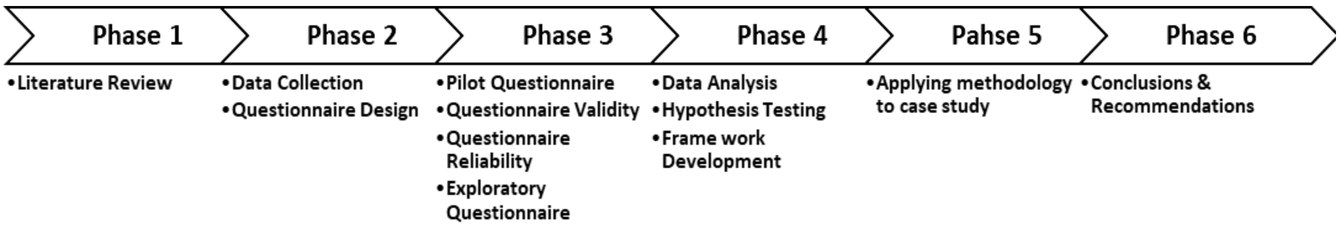


Figure 1 Flow chart of the research methodology

In the first phase: The research methodology was demonstrated throughout the literature review through communications with project stakeholders, the coordination of different disciplines in the construction field, and the impact of risks on the project objectives. These risks are the most prevalent ones that the construction industry faces, and failing to manage them has a detrimental effect on the project's goals. These hazards are mitigated by using building information modeling as a communication and coordination tool.

In the second phase: The quantitative approach method was chosen in the second phase of the study over the qualitative approach due to the numerical data being more appropriate for the research than the descriptive data. A set of questions was created specifically for this. There were four key sections to the questionnaire. Section 1 provided general information on the respondents, their companies, and their construction-related experiences. This made it possible to categorize the respondents based on the scope of the projects and the backgrounds of their companies. Section 2 focused on the most common risks encountered in construction projects in order to assess their impact and look into the effects of two significant risks: the coordination of the many construction disciplines and stakeholder communications. The research attempted to investigate the role of BIM in mitigating those two risks. Section 3 studied tools and techniques used by project managers to avoid or mitigate project risks. Section 4 was prepared for managers to figure out if they use BIM technology or not, to what extent, how they found the effect of using BIM as a tool to manage many risks in construction projects, and the barriers to BIM implementation.

In the third phase, two stages of data analysis were conducted; testing hypotheses and addressing exploratory research questions. Initially, ten individuals representing contractors, consultants, clients, and project managers were included in the sample group that received a pilot questionnaire. Two engineers, two project managers, two BIM managers, two management consultants, and two clients participated in the pilot questionnaire's distribution. According to the participants, the questionnaire was clear and simple to complete. However, the results of the pilot survey showed that while some of the questions concerning the risks associated with the construction projects were indicative, others were overly broad. A statistical computer program was used to analyze the validity and dependability (IBM-SPSS Statistics V.25 software). The validity of the pilot questionnaire was tested by examining the content validity; Criterion Related Validity and structure validity for each section and for the whole questionnaire were also tested to measure the correlation coefficient between sections, which have the same Likert scale as shown in Table 1. Table 1 explains the correlation coefficient for each of the questionnaire's components as well as the other sections. Since all of the fields' correlation coefficients were highly significant at α = 0.01, and the p-values were less than 0.01, it is acceptable to say that the fields can be measured.

Table 1 Validity Test of Pilot Questionnaire (Correlations)

Correlations			**S3 Effectiveness of Using Software in Risk Management**	**S2 Risks in Construction Projects**
Spearman's rho	S3 Effectiveness of Using Software in Risk Management	Correlation Coefficient	1.000	-.460**
		Sig. (2-tailed)	0.0.	.000
	S2 Risks in Construction Projects	Correlation Coefficient	-.460**	1.000
		Sig. (2-tailed)	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

In the fourth phase: Statistical analysis was the fourth step of the research technique, where data was gathered based on the problem statement and literature evaluation to establish a framework that would be used in AEC firms. IBM-SPSS STATISTICS version 25 was used to examine the resultant data, and the normality test (Kolmogorov Smirnov/Shapiro Wilk) was one of the statistical tests that were used. The test can be used to evaluate two independent groups' frequency distributions against each other or the frequency distribution of one group against a theoretical distribution [34]. The paired-samples t-test compares the mean scores for the same group under two different conditions, while the independent-samples t-test is a process used to make a comparison between two independent variables. The Mann-Whitney test is utilized to investigate variations between the medians of two datasets. When the values in the sample deviate from the normal distribution, it can be used in place of a t-test for independent samples [35]. A tool for analyzing group differences when the dependent variable is measured at a nominal level is the Chi-Square Test. A tool for determining the degree of linear association or correlation between two independent variables is the Spearman correlation coefficient Factors Ranking (Relative Importance Index (RII)). Determining the relative importance of the various components was the analysis's goal [36]. The sum of the respondents' scores for each component determines the factor's score.

The goal of the methodology's fifth phase was to apply the use of building information modeling as a risk management tool to a real project in order to confirm the tool's function and its influence on potential risks that may arise during the design phase. This demonstrated the usefulness of the tool and how well it can be used to manage risks.

The sixth and the final phase of the research methodology included the conclusion of applying the building information modeling technology in construction field to mitigate project risks.

4.1. The Reliability Test (Cronbach's Alpha Coefficient)

The Cronbach's alpha coefficient (α) is one of the most popular tests for assessing quantitative data in questionnaires. When used to assess the reliability of a questionnaire, this test yielded a result of 0.931, which shows that the data were internally consistent and could be used for additional analysis as well as the consistency of the questionnaire. A revised questionnaire was given to the sample population at the conclusion of this phase, and information on responses was gathered. There are 671 people in total who can be found in the targeted area (456 construction companies and 215 consulting organizations). In order to determine a sample size of the population that is statistically representative, the number was determined using the following formula:

$$SS = \frac{Z^2 * (P) * (1 - P)}{e^2} \tag{1}$$

SS: calculated sample size.
Z: value for the confidence level (e.g. 1.64 for 95% confidence level)
p: percentage picking a choice, expressed as decimal (0.2 used for sample size needed)
E: confidence interval, expressed as decimal (e.g., o.08 = ±8%)

Compensating with the above mentioned values resulted in, SS = 68 as required sample size, the total gathered number was 80 respondents. There were a total of 20 consultants and 60 contractors. The questionnaire was distributed using the 'Survey-Monkey' website in both English and Arabic and transmitted by email to respondents who were involved in the construction projects field. The number of responses was 153; not all the respondents completed the questionnaire until the last section, and the completed responses were 78. The collection of answers was done by the website.

5.0 RESULTS AND DISCUSSIONS: ANALYTICAL STATISTICS

The replies to the questionnaire were provided in one of five binary, Likert scale, or continuous formats. A suitable statistical test was administered using SPSS depending on the type of data that was obtained. The acquired information was divided into two sets of building information models; both users and non-users.

5.1. Normality Test (Kolmogorov Smirnov / Shapiro Wilk)

This test was predicated on the following assumptions: Alternative Hypothesis H1: The data do not follow the normal distribution, and Null Hypothesis H0: The data follow a normal distribution. The null hypotheses was accepted because the results of the Shapiro-Wilk and Kolmogorov-Smirnov tests for normality indicate that the data on risks in building projects were normally distributed because the significance level values were greater than 0.05.

Table 2 Normality Test (For Section two (S2))

	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
S2 Risks in Construction Projects	0.061	78	0.200*	0.982	78	0.317

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Since the significance level values for the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality were less than 0.05, the null hypothesis was rejected and the alternative hypothesis was accepted. These results indicate that the data on the efficacy of using the software in risk management is not normally distributed.

Table 3 Normality Test (For Section three (S3))

	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
S3 Risks in Construction Projects	0.181	78	0.000*	0.929	78	0.000

S3: Section 3 of the questionnaire (Effectiveness of Using Software in Risk Management).
a. Lilliefors Significance Correction

5.2. T-Test

The assumptions of the test are: Null Hypothesis H0: The total rank of risks in building projects does not significantly differ between BIM users and non-users. Additionally, the alternative hypothesis (H1) states that there is a noteworthy distinction between BIM users and non-users in the overall rank of hazards in building projects. The data on risks in construction projects were not agreed upon by the two groups of BIM users and non-users, according to the results of the independent t-test for agreement. Since the significance level values are less than 0.05, the null hypothesis was rejected in this case and the alternative hypothesis was accepted.

Table 4 Independent Samples Test (T-test) for Section Two (S2)

		t-test for Equality of Means						
		t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
S2 Risks in Construction Projects	Assuming Equal Variances	4.994	76	0.000	0.60347	0.12084	0.36280	0.84414
	Not Assuming Equal Variances	4.958	60.247	0.000	0.60347	0.12172	0.36002	0.84693

S2: Section two of the questionnaire (Risks in Construction Projects)

5.3. Spearman Correlation Coefficient

Since the test looks at medians rather than means, its influence is eliminated if there are one or two outliers in the data. The correlation coefficient falls between +1 and -1, where a perfect positive relationship (agreement) is indicated by a value of +1 and a perfect negative relationship (disagreement) is indicated by a value of -1. The Spearman's rank correlation coefficient (ρ) between the two main variables of section two, the risks in construction projects, and section three, the effectiveness of the software in risk management, was (-0.46), which means that there was a significant correlation between the two variables. Inverse proportionality is indicated by the negative value of the correlation coefficient's (ρ).

Table 5 Spearman Correlation Coefficient Between Section Two (S2) and Section Three (S3)

		S2 Risks in Construction Projects	**Effectiveness of Using Software in Risk Management**
Spearman's rho	Correlation Coefficient	1.000	-0.460**
	Sig. (2-tailed)	0.000	0.000
	N	78	78

**. Correlation is significant at the 0.01 level (2-tailed).

5.4. Descriptive Statistics

The descriptive statistics for respondents illustrate that not all the respondents completed the questionnaire until the last section, as shown in Figure 2-A. According to the organization roles of the respondents and the percentage of each role, it has been observed that the contracting organization occupies about 45% and the consultant organization comes in second place by 28%, as shown in Figure 2-B.

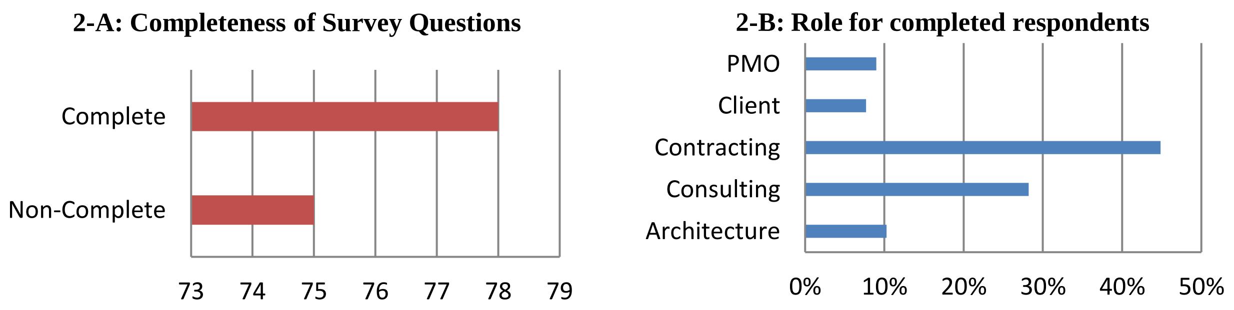


Figure 2-A and 2-B Distribution of the respondents

From the responses on the probability of week communication and the miss coordination risks and the consequence of these risks on project duration, it was shown that the range of (RII) for the BIM non-user group was 0.46 and 0.49, respectively, and the importance level was medium for both risks, as shown in Table 8. While in the BIM-user group, the RII was 0.33 and 0.39 for the same risks, and the importance level was medium-low for both risks, the relative index importance (RII) for the BIM-user group was less than that of the that of the BIM non-users' group, so they faced these risks less than the BIM non-users' group.

Table 6 Importance Index for Risk Factors Impact Time (BIM-Nonusers)

Factors	N	Mean	Std. Deviation	Relative Index (RII)	Importance Level	Rank
S2Q12 Risk: Weakness in Communication between stakeholders / Time / Score Category	48	2.29	1.01	0.46	Medium	6
S2Q12 Risk: Not coordinated design / Time / Score Category	48	2.46	1.01	0.49	Medium	4

Table 7 Importance Index for Risk Factors Impact Time (BIM-Users)

Factors	N	Mean	Std. Deviation	Relative Index (RII)	Importance Level	Rank
S2Q12 Risk: Weakness in Communication between stakeholders / Time / Score Category	30	1.67	0.66	0.33	Medium - Low	8
S2Q12 Risk: Not coordinated design / Time / Score Category	30	1.97	0.85	0.39	Medium - Low	4

On the other hand, the result of the probability and impact of these risks on the project budget was very close to the previous data in Tables 6 and 7. These results illustrate that the relative index of these risks for the BIM non-users group is higher than the relative index of the same risks for the BIM users group, as shown in Tables 8 and 9.

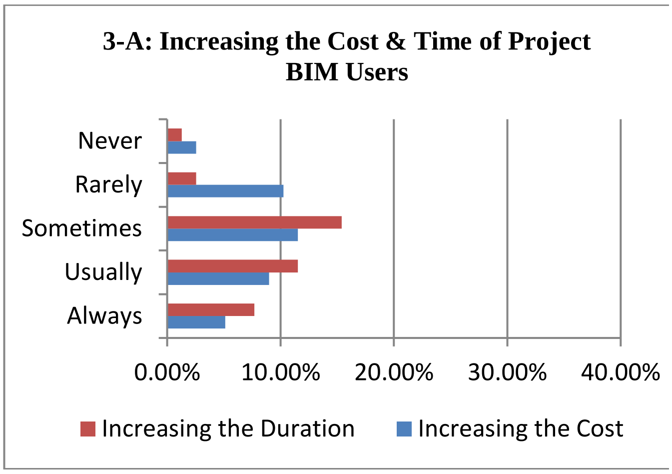
Table 8 Importance Index for Risk Factors Impact Cost (BIM-Nonusers)

Factors	N	Mean	Std. Deviation	(RII)	Importance Level	Rank
S2Q13 Risk: Weakness in Communication between stakeholders / Cost / Score Category	48	2.44	1.15	0.49	Medium	4
S2Q13 Risk: Not coordinated design / Cost / Score Category	48	2.56	1.15	0.51	Medium	2

Table 9 Importance Index for Risk Factors Impact Cost (BIM-Users)

Factors	N	Mean	Std. Deviation	(RII)	Importance Level	Rank
S2Q13 Risk: Weakness in Communication between stakeholders / Cost / Score Category	30	1.63	0.85	0.33	Medium - Low	8
S2Q13 Risk: Not coordinated design / Cost / Score Category	30	2.00	1.20	0.40	Medium - Low	1

Questionnaire responses regarding the frequency of cost and time overruns in projects indicate that BIM non-users experience higher rates of these overruns compared to BIM users, as illustrated in Figures 3.A and 3.B.



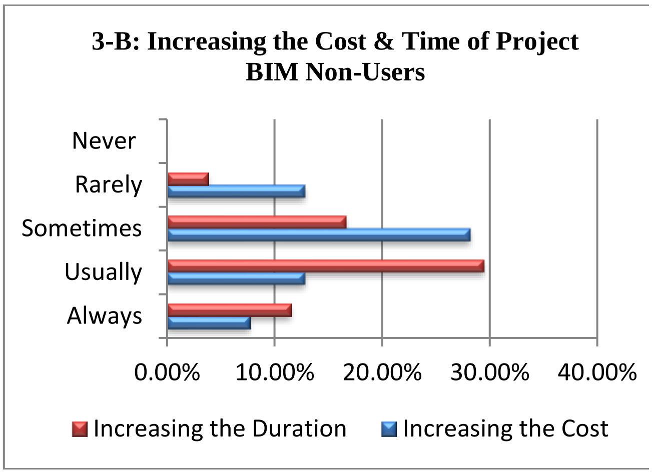
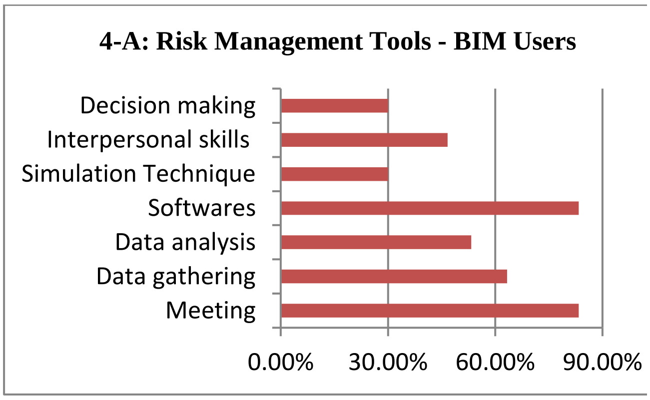


Figure 3-A and 3-B Project performance and risk management

To further analyze risk management practices and tool usage in construction projects, Figure 4.A demonstrates that BIM users who encounter fewer risks and implement risk management early in the project lifecycle are more likely to utilize software and simulation techniques compared to BIM non-users, as depicted in Figure 4.B.



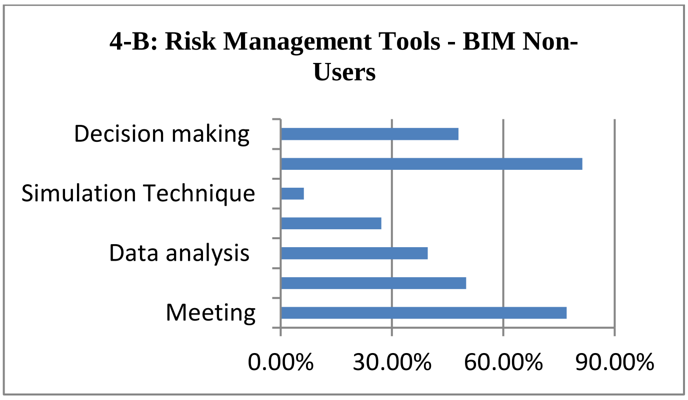


Figure 4-A and 4-B Risk management tools

While opinions on BIM's utility across various management domains, such as risk, time, cost, and communication, varied as illustrated in Figure 5.A, a majority of respondents recognized BIM's overall effectiveness in project management, with 42% strongly endorsing its role in risk management, as depicted in Figure 5.B. Figure 5.C presents the perspectives of respondents on which parties should initiate BIM implementation in construction projects. The results show that the majority chose the client in the first place, followed by the government and the PMO, so they agreed that the setting of using BIM in construction projects depends on the authorized parties. The effectiveness of adopting BIM in the various stages of the project life cycle is depicted in Figure 5.D, with the design and construction phases displaying the highest percentage of effectiveness.

Respondents indicated that BIM can be utilized for multi-trade coordination, design visualization, and quantity take-off during the pre-construction phase, encompassing the feasibility, initiation, and design stages, as illustrated in Figure 6.A. The uses of BIM vary depending on the project life cycle. As Figure 6.B illustrates, majority of BIM applications throughout the construction phase, which includes the tendering and construction phases, were for managing and controlling the site's activity execution through the use of model layout and status and progress monitoring. On the other hand, in the post-construction phase, encompassing handover and operations and maintenance, respondents identified BIM applications in creating as-built models and incorporating maintenance and operational data, as visualized in Figure 6.C. Finally, the most effective uses of BIM, according to the voting of respondents, were clash detection, coordination, and communication, as shown in Figure 6.D.

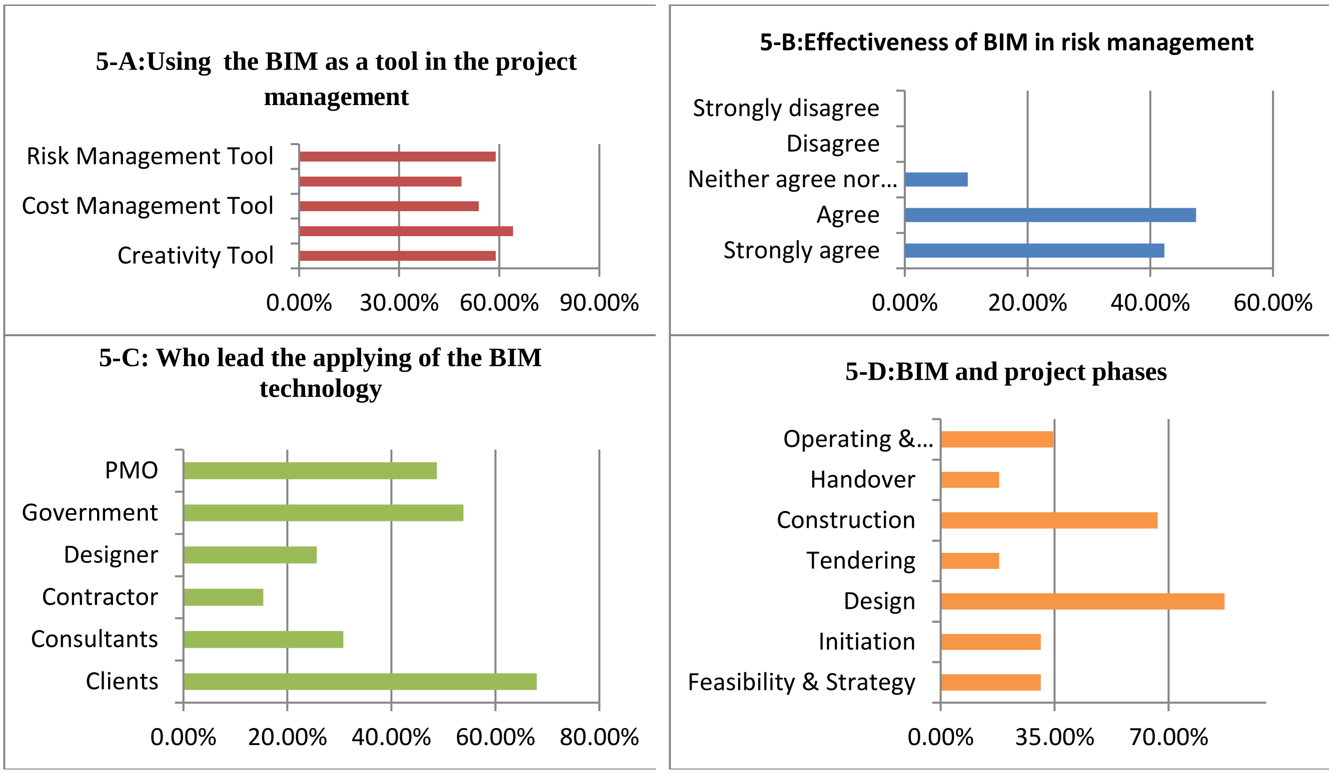


Figure 5A, 5-B, 5-C and 5-D BIM and project management

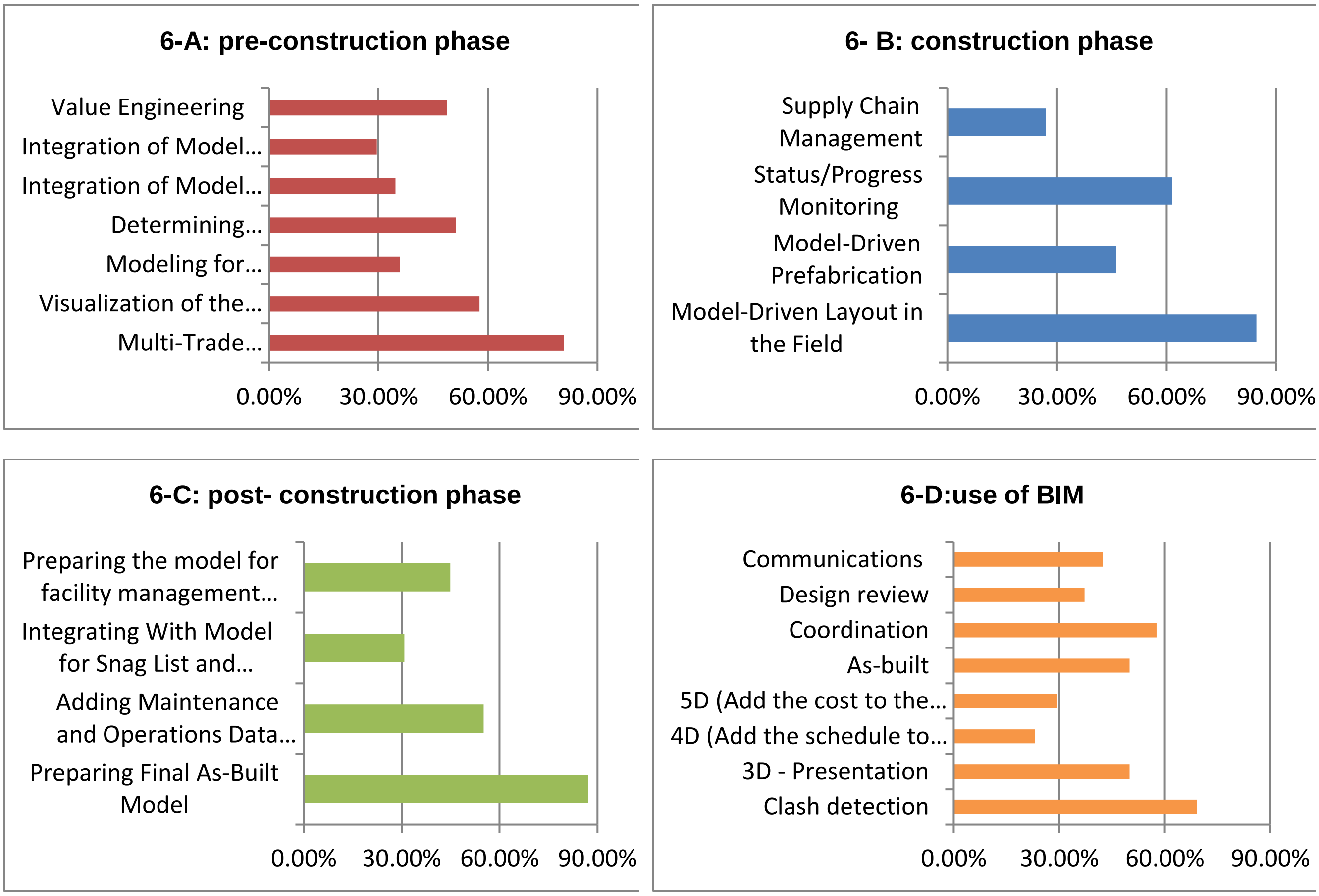


Figure 6-A, 6-B, 6-C and 6-D Uses of BIM during project life cycle

6.0 APPLYING THE PROPOSED METHODOLOGY ON A CASE STUDY

The project title is Sales, Services, and Showroom for Lexus Vehicles (SSS). The project was to design a 4000 m2 car showroom and workshop on the ground and mezzanine floors. The ground floor of this location has an open area in front for parking and unloading new cars, a large showroom with a car display, a car service area, a service workshop, and a ramp leading to a terrace where new cars can be stored. Office space is also available on the mezzanine floor. The project was built in Riyadh, Saudi Arabia, with a budgeted cost of 24,443,725 SAR in 490 days. The owner of the project was the REIT Fund, and it was eventually delivered to Lexus Saudi Arabia.

Figure 7 Real pictures of the Project

6.1. Develop the Schedule by Primavera P6 Professional

For the case study, the original project duration and required resources were estimated and determined using the Critical Path Method (CPM) in Primavera P6 Professional version 16.1 software. The work breakdown structure (WBS) was created according to engineering, procurement, and construction (EPC). The engineering part of the WBS is divided into design, shop drawing, and as-built drawing. After developing the schedule, the project's original duration was 490 working days, as shown in Figure 8.A. Then the resource was loaded to determine the project's planned cost, which was 24,443,725 SAR, as shown in Figure 8.B.

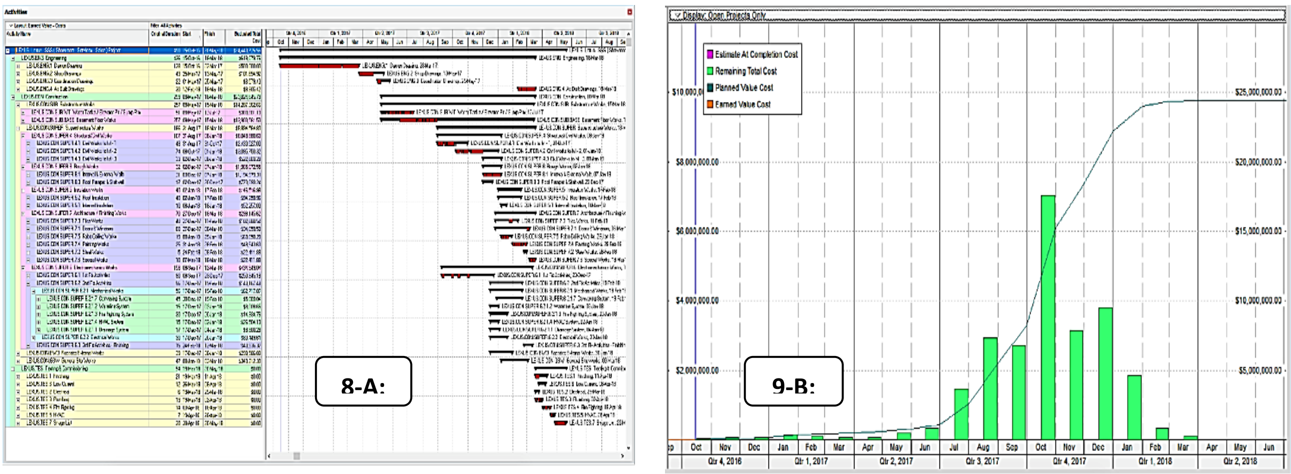


Figure 8-A and 8-B Primavera P6 Time Schedule and cost histogram

6.2. Project Risk Management by Primavera Risk Analysis

The Project Management Institute (PMI) defines risk as an uncertain occurrence or condition that, if it occurs, has an impact on one or more project objectives, including scope, schedule, cost, and quality. This definition is adopted by the risk methodology (PMBOK Guide, 6th edition). According to the PMBOK 5th edition, the risk management process consists of six steps: plan risk management, identify risks, perform qualitative risk analysis, perform quantitative risk analysis, plan risk responses, and monitor and control risks.

6.3. Plan Risk Management

The risk management plan was developed by the project management team through brainstorming sessions and meetings during planning. The risk breakdown structure (RBS) and likelihood and impact matrix were two of the most crucial parts of the plan. The data were entered in Primavera Risk Analysis Release 8.7 software, as shown in Figure 9.

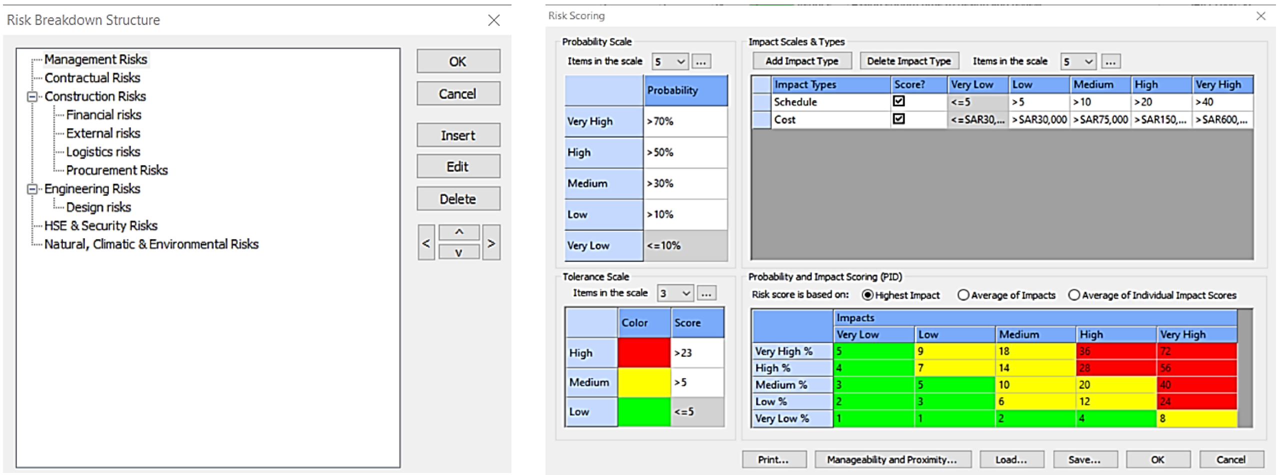


Figure 9 Risk breakdown structure and scoring

6.4. Identify Risks

The process of identifying the risks that could affect the project's goals and their characteristics during the course of the project's life cycle is known as risk identification. Data gathering techniques such as brainstorming, checklists, document analysis, and meetings were employed to identify potential risks that could impact project objectives. This paper focused on biases and errors in cost and time estimation, as well as a short list of risks related to the main problem statement of this paper, which were communication and coordination challenges between different project disciplines. The paper identified ten risks that were included in the risk register, as shown in Table 10.

Table 10 Suggested List of Risks

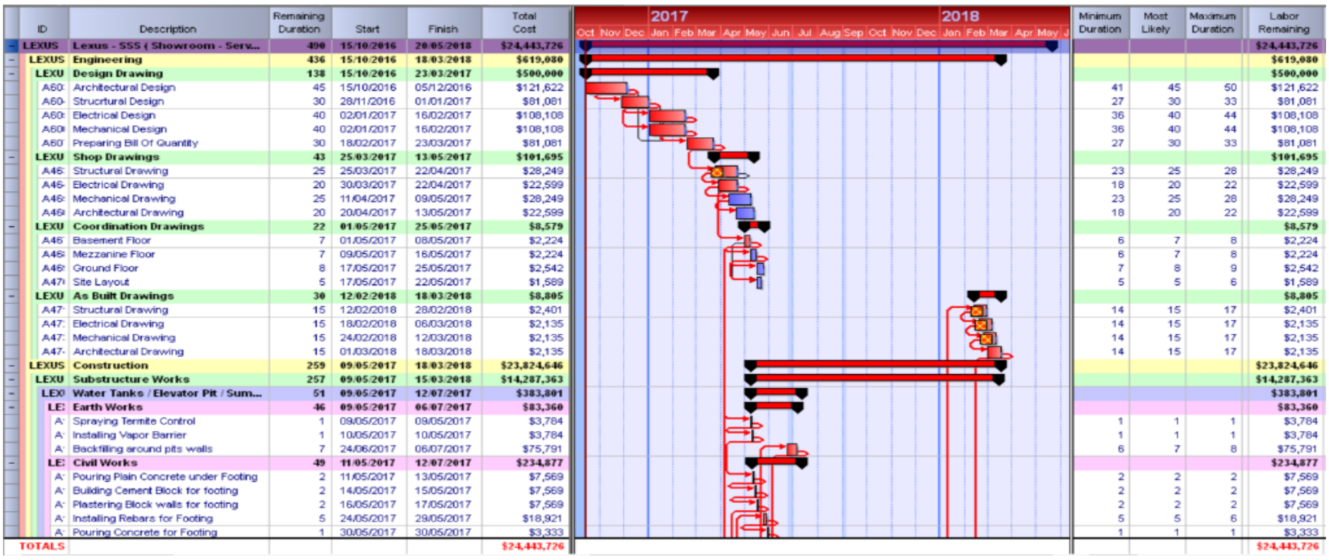
ID	Type	Title
RISK1	Threat	Mistakes in preliminary design
RISK2	Threat	Rush design
RISK3	Threat	Awarding the design to unqualified designers
RISK4	Threat	Delay in Revising/approving design documents
RISK5	Threat	Delay in Revising/approving shop drawings and materials
RISK6	Threat	Not coordinated design (structural, mechanical, electrical, etc.)
RISK7	Threat	Changes in the design and specifications of the project materials
RISK8	Threat	Inaccurate quantities
RISK9	Threat	Lack of consistency between bill of quantities and drawings
RISK10	Threat	Inadequate specifications

6.5. Perform Qualitative Risk Analysis

A qualitative risk analysis assessment was applied to those ten risks to prioritize them in order to facilitate the reduction of uncertainty about risks and focus on high-priority risks, as shown in Table 10.

6.6. Develop Schedule Risk Model

The schedule was imported from Primavera P6 Software to Primavera Risk Analysis as shown in Figure 10.

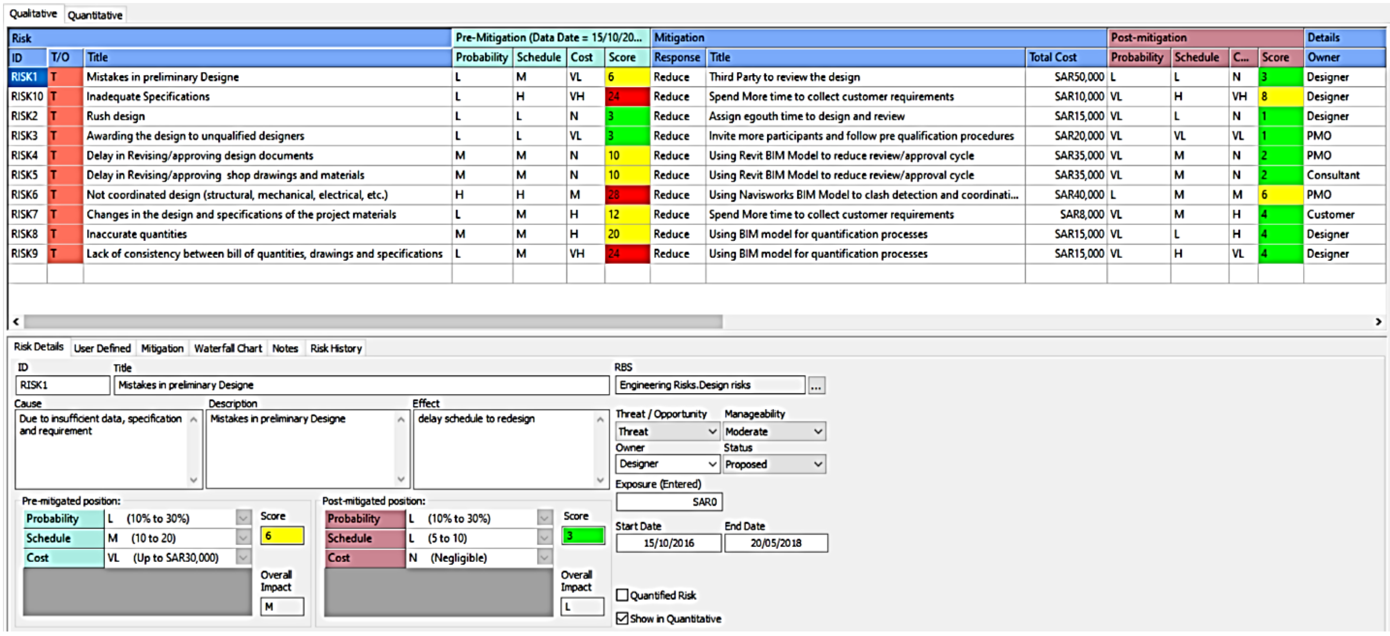


ID	Description	Remaining Duration	Start	Finish	Total Cost	Minimum Duration	Most Likely	Maximum Duration	Labor Remaining
LEXUS	Lexus - SSS (Showroom - Serv...	490	15/10/2016	20/05/2018	$24,443,726				$24,443,726
LEXUS	Engineering	436	15/10/2016	18/03/2018	$619,080				$619,080
LEXU	Design Drawing	138	15/10/2016	23/03/2017	$500,000				$500,000
A60	Architectural Design	45	15/10/2016	05/12/2016	$121,622	41	45	50	$121,622
A60	Strucrtural Design	30	28/11/2016	01/01/2017	$81,081	27	30	33	$81,081
A60	Electrical Design	40	02/01/2017	16/02/2017	$108,108	36	40	44	$108,108
A60	Mechanical Design	40	02/01/2017	16/02/2017	$108,108	36	40	44	$108,108
A60	Preparing Bill Of Quantity	30	18/02/2017	23/03/2017	$81,081	27	30	33	$81,081
LEXU	Shop Drawings	43	25/03/2017	13/05/2017	$101,695				$101,695
A46	Structural Drawing	25	25/03/2017	22/04/2017	$28,249	23	25	28	$28,249
A46	Electrical Drawing	20	30/03/2017	22/04/2017	$22,599	18	20	22	$22,599
A46	Mechanical Drawing	25	11/04/2017	09/05/2017	$28,249	23	25	28	$28,249
A46	Architectural Drawing	20	20/04/2017	13/05/2017	$22,599	18	20	22	$22,599
LEXU	Coordination Drawings	22	01/05/2017	25/05/2017	$8,579				$8,579
A46	Basement Floor	7	01/05/2017	08/05/2017	$2,224	6	7	8	$2,224
A46	Mezzanine Floor	7	09/05/2017	16/05/2017	$2,224	6	7	8	$2,224
A46	Ground Floor	8	17/05/2017	25/05/2017	$2,542	7	8	9	$2,542
A47	Site Layout	5	17/05/2017	22/05/2017	$1,589	5	5	6	$1,589
LEXU	As Built Drawings	30	12/02/2018	18/03/2018	$8,805				$8,805
A47	Structural Drawing	15	12/02/2018	28/02/2018	$2,401	14	15	17	$2,401
A47	Electrical Drawing	15	18/02/2018	06/03/2018	$2,135	14	15	17	$2,135
A47	Mechanical Drawing	15	24/02/2018	12/03/2018	$2,135	14	15	17	$2,135
A47	Architectural Drawing	15	01/03/2018	18/03/2018	$2,135	14	15	17	$2,135
LEXUS	Construction	259	09/05/2017	18/03/2018	$23,824,646				$23,824,646
LEXU	Substructure Works	257	09/05/2017	15/03/2018	$14,287,363				$14,287,363
LEX	Water Tanks / Elevator Pit / Sum...	51	09/05/2017	12/07/2017	$383,801				$383,801
LE	Earth Works	46	09/05/2017	06/07/2017	$83,360				$83,360
A	Spraying Termite Control	1	09/05/2017	09/05/2017	$3,784	1	1	1	$3,784
A	Installing Vapor Barrier	1	10/05/2017	10/05/2017	$3,784	1	1	1	$3,784
A	Backfilling around pits walls	7	24/06/2017	06/07/2017	$75,791	6	7	8	$75,791
LE	Civil Works	49	11/05/2017	12/07/2017	$234,877				$234,877
A	Pouring Plain Concrete under Footing	2	11/05/2017	13/05/2017	$7,569	2	2	2	$7,569
A	Building Cement Block for footing	2	14/05/2017	15/05/2017	$7,569	2	2	2	$7,569
A	Plastering Block walls for footing	2	16/05/2017	17/05/2017	$7,569	2	2	2	$7,569
A	Installing Rebars for Footing	5	24/05/2017	29/05/2017	$18,921	5	5	6	$18,921
A	Pouring Concrete for Footing	1	30/05/2017	30/05/2017	$3,333	1	1	1	$3,333
TOTALS					$24,443,726				$24,443,726

Figure 10 Primavera risk analysis model

6.7. Updating Risk Register

A risk register was created during the risk identification process, and it is updated based on data gathered during the qualitative risk analysis process. The risk register included risk factors, the type of risk (threat or opportunity), the likelihood of occurrence, and the potential impact of the ten identified risks on the project's cost and schedule goals. The hazards were then prioritized using the risk score, as indicated in Figure11.



Risk			Pre-Mitigation (Data Date = 15/10/20...				Mitigation			Post-mitigation				Details
ID	T/O	Title	Probability	Schedule	Cost	Score	Response	Title	Total Cost	Probability	Schedule	C...	Score	Owner
RISK1	T	Mistakes in preliminary Designe	L	M	VL	6	Reduce	Third Party to review the design	SAR50,000	L	L	N	3	Designer
RISK10	T	Inadequate Specifications	L	H	VH	24	Reduce	Spend More time to collect customer requirements	SAR10,000	VL	H	VH	8	Designer
RISK2	T	Rush design	L	L	N	3	Reduce	Assign egouth time to design and review	SAR15,000	VL	L	N	1	Designer
RISK3	T	Awarding the design to unqualified designers	L	L	VL	3	Reduce	Invite more participants and follow pre qualification procedures	SAR20,000	VL	VL	VL	1	PMO
RISK4	T	Delay in Revising/approving design documents	M	M	N	10	Reduce	Using Revit BIM Model to reduce review/approval cycle	SAR35,000	VL	M	N	2	PMO
RISK5	T	Delay in Revising/approving shop drawings and materials	M	M	N	10	Reduce	Using Revit BIM Model to reduce review/approval cycle	SAR35,000	VL	M	N	2	Consultant
RISK6	T	Not coordinated design (structural, mechanical, electrical, etc.)	H	H	M	28	Reduce	Using Navisworks BIM Model to clash detection and coordinati...	SAR40,000	L	M	M	6	PMO
RISK7	T	Changes in the design and specifications of the project materials	L	M	H	12	Reduce	Spend More time to collect customer requirements	SAR8,000	VL	M	H	4	Customer
RISK8	T	Inaccurate quantities	M	M	H	20	Reduce	Using BIM model for quantification processes	SAR15,000	VL	L	H	4	Designer
RISK9	T	Lack of consistency between bill of quantities, drawings and specifications	L	M	VH	24	Reduce	Using BIM model for quantification processes	SAR15,000	VL	H	VL	4	Designer

Figure 11 Risk register

6.8. Perform Quantitative Risk Analysis

The technique of numerically evaluating the impact of identified risks on the overall project objectives through modeling and simulation is known as quantitative risk analysis.

6.9. Applying Uncertainty

As illustrated in Figures 12 and 13, the duration risk tool in Primavera risk analysis was used to apply the uncertainty that arises from brainstorming sessions and error estimation to the schedule activities' time and cost. This was the first step in the quantitative risk analysis process. The uncertainty ranges were set at 90% for the minimum, 100% for the most likely, and 110% for the maximum values. When values were known for the maximum, minimum, and most likely, the triangular distribution was utilized.

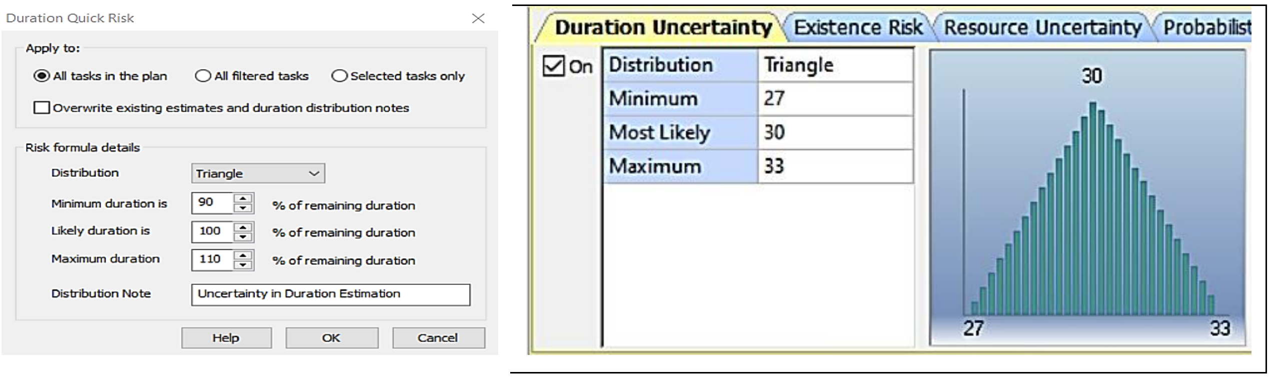


Figure 12 Uncertainty in duration estimations

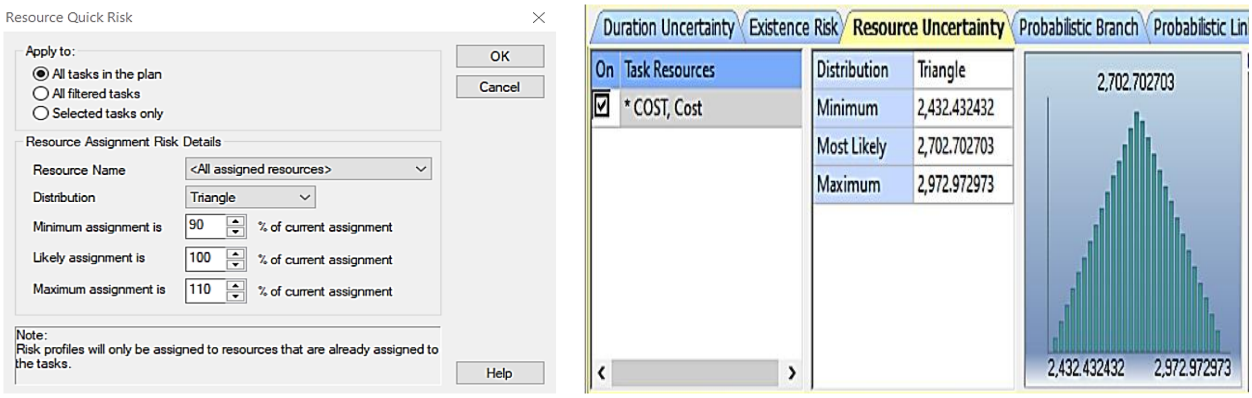


Figure 13 Uncertainty in resource estimations

6.10. Risk Register Integration with Schedule

The purpose of this Primavera Risk Analysis phase was to integrate risk occurrences into the Monte Carlo simulation and project timeline. Risk events were essentially handled by the Primavera Risk program as probabilistic tasks with logical connections to the schedule. As seen in Figure 14, the risks were connected to the schedule in the risk registry. The wizard activated and started the process of transforming risk events into probabilistic activities, as shown in Figure 15.A. As seen in Figure 15.B, there were two risk plan scenarios that were used; pre-mitigation and post-mitigation. Before putting mitigation measures into action, the risk analysis was studied using the pre-migrated scenario. In spite of this, the second scenario (the post-mitigating scenario) was taken into consideration. The risk analysis was examined following the implementation of the mitigating measures. The timetable was connected to the priority risk variables in scenarios, the post-mitigation scenario, and the pre-mitigation scenario, as indicated by the right side of Figure15.B.

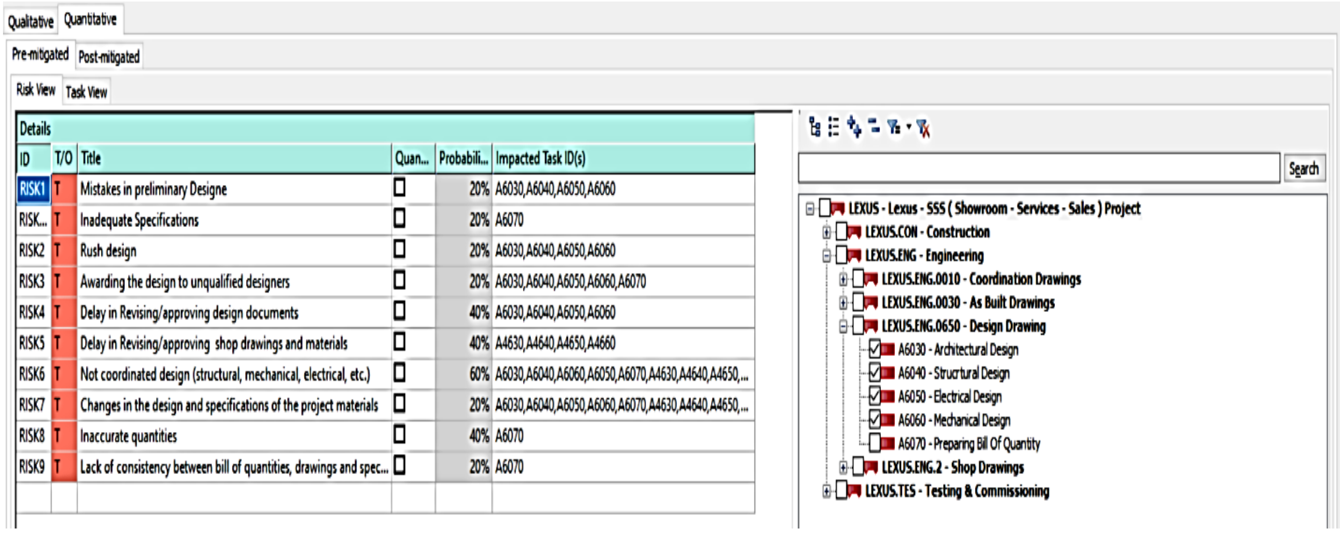


Figure 14 Updated risk register

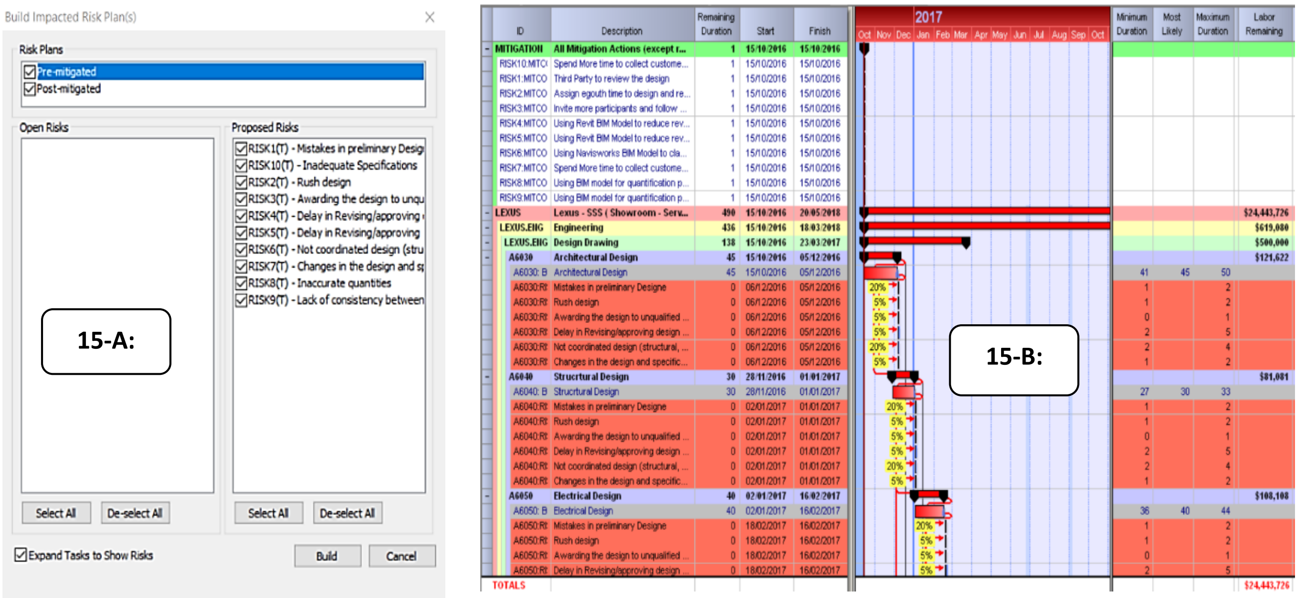


Figure 15.A and 15.B Build impacted risk plans and updated risk analysis model

6.11. Running Risk Analysis and Simulation

The Monte Carlo technique was used to execute simulations. The project model was computed repeatedly, and each time, input values such as activity durations or cost estimates were selected at random from the probability distributions of these variables. The iterations were used to calculate a histogram, such as the total cost or the completion date. Cost estimations were used in a simulation for a cost-risk analysis. In our case study, Oracle Primavera Risk Analysis was utilized for schedule risk analysis, including the development of a schedule network diagram and Monte Carlo simulation modeling, as illustrated in Figure 16. The test analysis run covered 1000 iterations, which reflected the simulation processes that were being carried out.

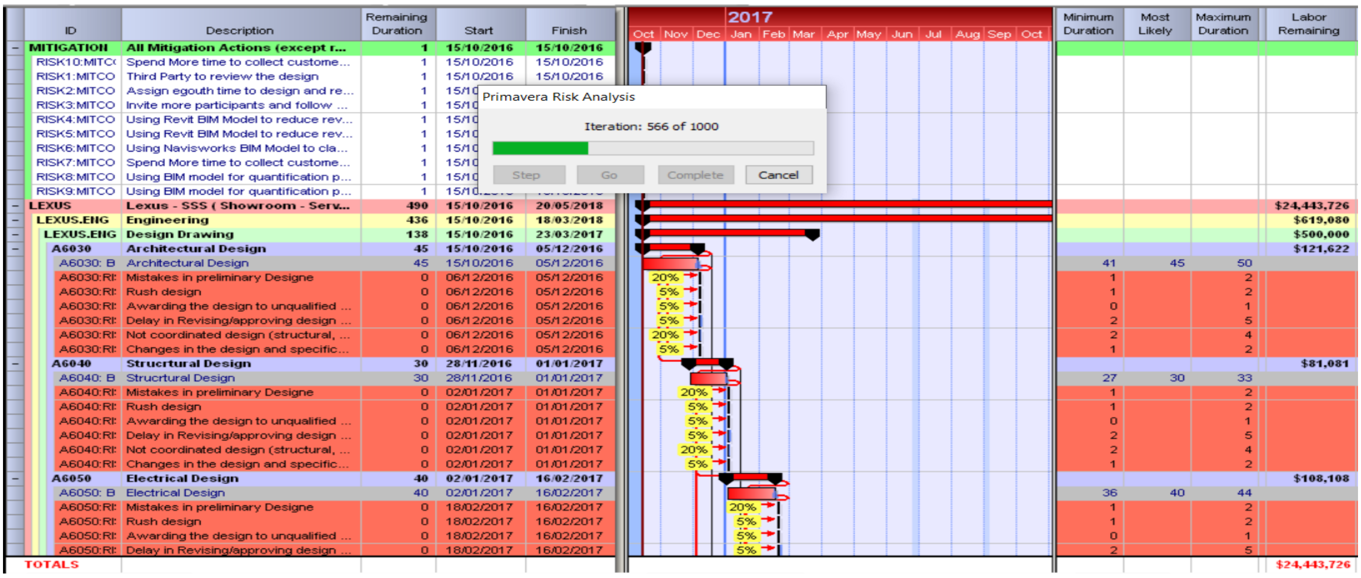


Figure 16 Risk analysis simulation

6.12. Plan Risk Responses

The process of creating options and actions to increase opportunities and lessen threats to project objectives is known as Plan Risk Responses.

To manage risks, project teams can employ several strategies. Risk avoidance involves eliminating threats or shielding the project from their impact. Risk transference shifts potential negative consequences to a third party. Risk mitigation reduces the likelihood or impact of risks occurring. Finally, risk acceptance acknowledges the risk but takes no proactive action unless it materializes. Figure 17 reflects the applied responses for risks and the cost of each response in the mitigation plan. The post-mitigation plan was then performed, and the new scores were calculated for the risks according to the selected responses.

Mitigation			Post-mitigation				Details
Response	Title	Total Cost	Probability	Schedule	C...	Score	Owner
Reduce	Third Party to review the design	SAR50,000	L	L	N	3	Designer
Reduce	Spend More time to collect customer requirements	SAR10,000	VL	H	VH	8	Designer
Reduce	Assign egouth time to design and review	SAR15,000	VL	L	N	1	Designer
Reduce	Invite more participants and follow pre qualification procedures	SAR20,000	VL	VL	VL	1	PMO
Reduce	Using Revit BIM Model to reduce review/approval cycle	SAR35,000	VL	M	N	2	PMO
Reduce	Using Revit BIM Model to reduce review/approval cycle	SAR35,000	VL	M	N	2	Consultant
Reduce	Using Navisworks BIM Model to clash detection and coordinati...	SAR40,000	L	M	M	6	PMO
Reduce	Spend More time to collect customer requirements	SAR8,000	VL	M	H	4	Customer
Reduce	Using BIM model for quantification processes	SAR15,000	VL	L	H	4	Designer
Reduce	Using BIM model for quantification processes	SAR15,000	VL	H	VL	4	Designer

Figure 17 Risks responses

Probability and impact matrices illustrated that most risks were categorized in the yellow medium zone in the pre-mitigation stage. After implementing mitigation actions, these risks shifted towards the green area in the post-mitigation stage. As seen in Figure 18, it is evident that the scale was lowered and that the risk variables now fell within the low scale zone.

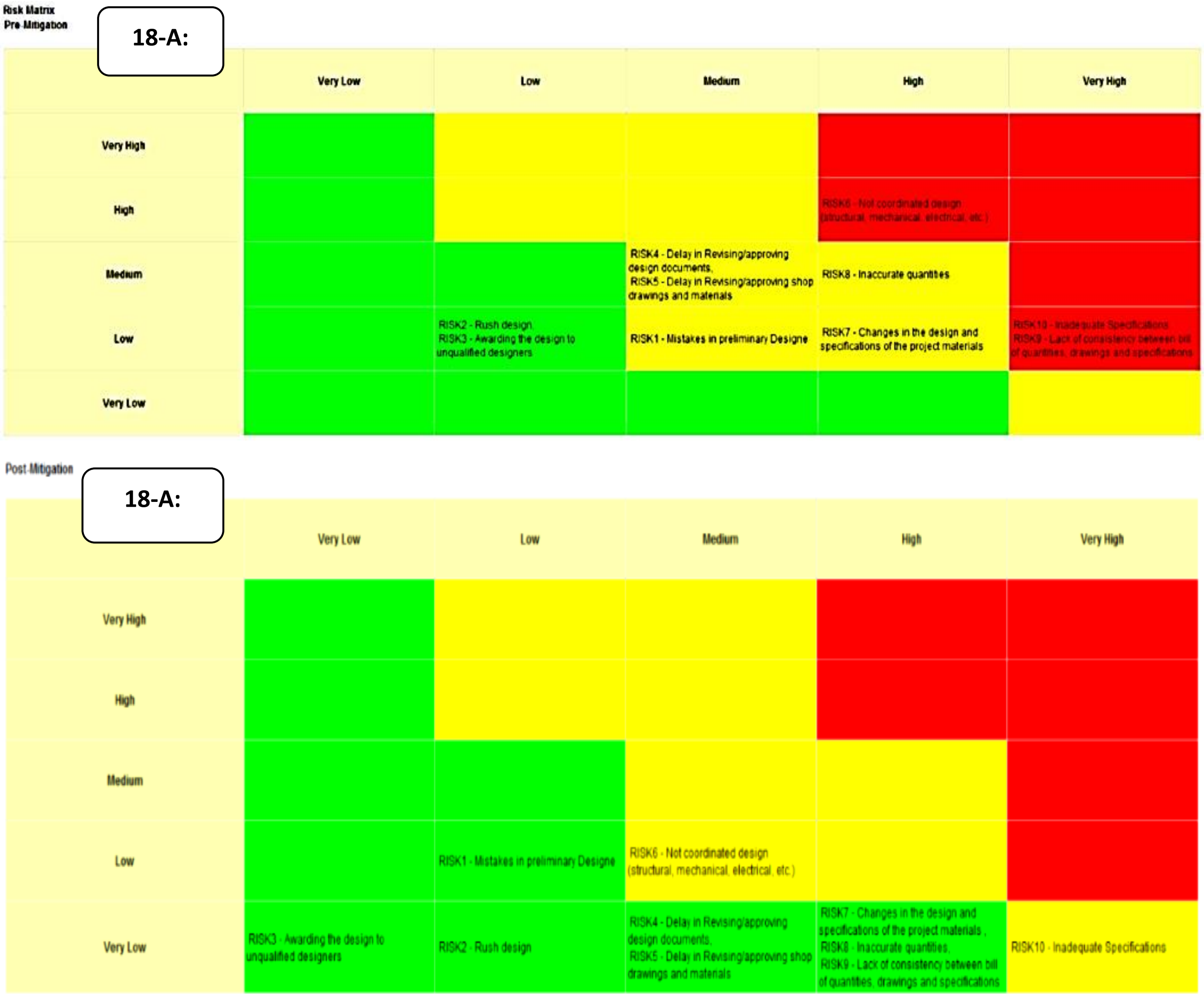


Figure 18-A and 18-B Risk matrix pre-mitigation and risk matrix post-mitigation

6.13. Original Plan (with Uncertainty in Cost Schedule)

The cumulative distribution histogram for the entire project, based on the initial plan (which considered only schedule and cost uncertainties without incorporating risk events), is presented in Figure 19. There was a 3% probability of completing the project on May 20, 2018. The likelihood of completing the entire project by May 30, 2018, was 50%. Figure 19.A indicates that a nine-day time contingency reserve was required to achieve an 80% confidence level in project completion. Consequently, there was an 80% probability that all project work can be finished by April 6, 2018. Figure 19B shows the deterministic cost, which was 24,443,726 SAR. There was an 80% probability that the total project completion cost will be 25,238,742 SAR.

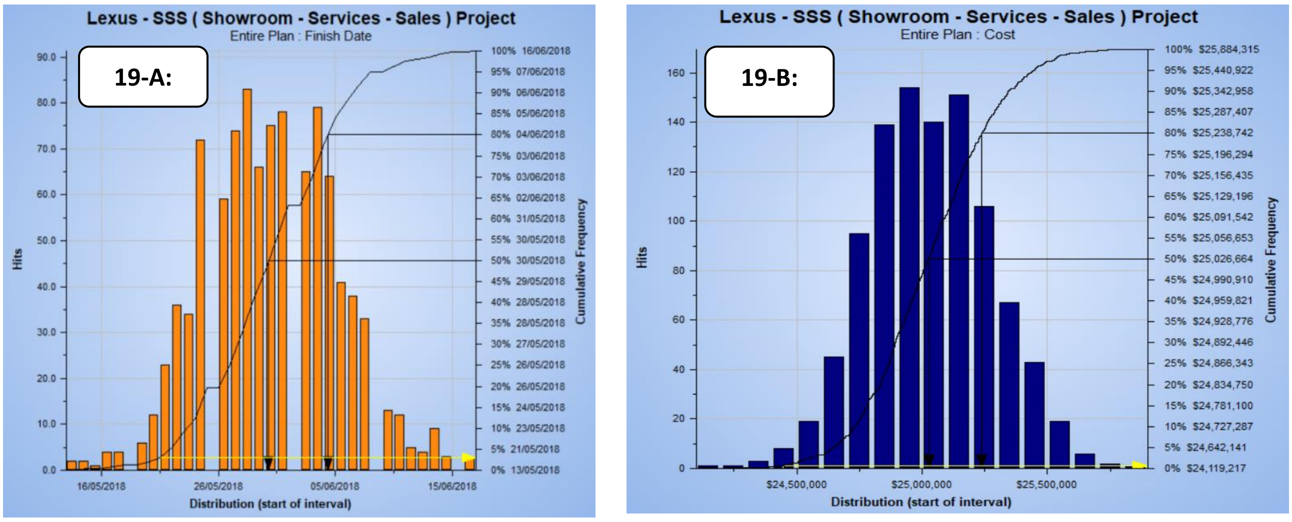


Figure 19-A and 19-B Original plan distribution histogram of finish date and cost

6.13.1. Pre-mitigation plan

Figure 20 represents the completion of the whole work cumulative distribution histogram after assigning risk events, which were identified in the risk register, to the project schedule. This histogram is the result of a pre-mitigation scenario before mitigating response actions. The deterministic date of May 20, 2018 indicates that the project can be completed at this date with a probability of <1%. There is a 50% probability of completing the entire project by July 2, 2018. To achieve an 80% confidence level in project completion, a 37-day time contingency reserve is necessary, resulting in an estimated completion date of July 17, 2018, as illustrated in Figure 20.A. Figure 20.B presents the histogram of the project's total completion cost. The deterministic cost was 24,443,726 SAR. The histogram shows that this cost can be used to complete the project with a probability of less than 1% for the entire set of works. With a 50% chance of success, the total project completion cost might be 25,677,511 SAR. With an 80% chance of success, the total project completion cost might come to 26,361,988 SAR. To achieve an 80% confidence level in project cost, an additional cost contingency reserve of 1,918,262 SAR is required.

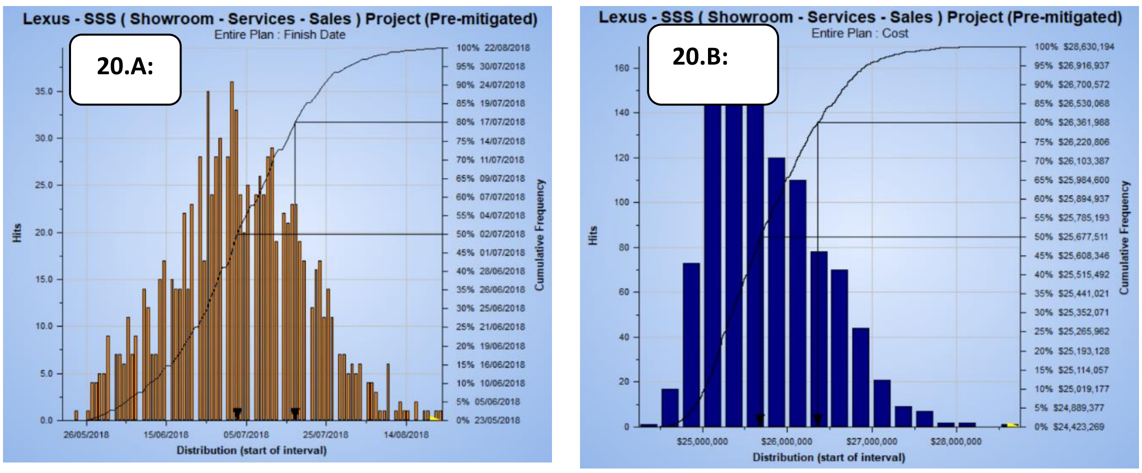


Figure 20.A and 20.B Pre-mitigation plan distribution histogram for finish date and cost

Sensitivity analysis was used to identify the risks that could have the greatest influence on the project by utilizing a tornado diagram, as shown in Figure 21 with RISK10. The biggest possible influence on the total cost and length of a project was inadequate specifications.

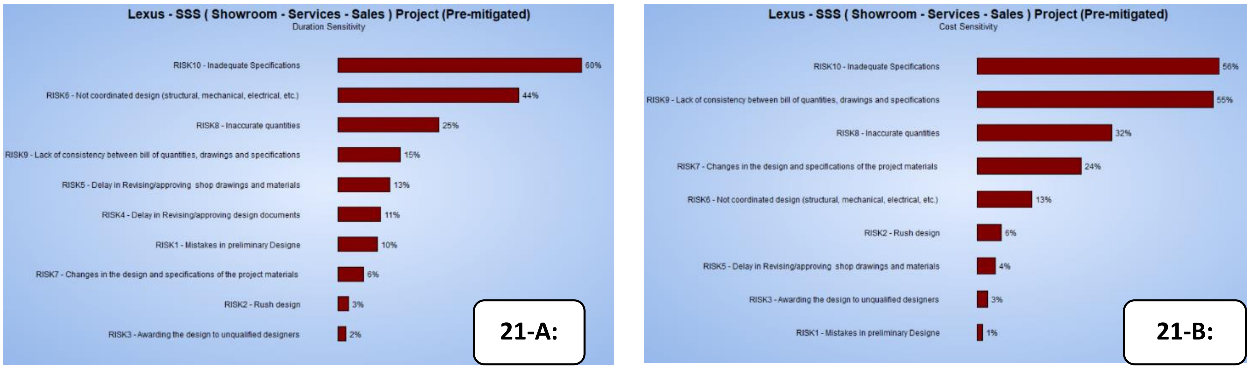


Figure 21 Sensitivity analysis (Tornado chart) for duration and cost

6.13.2. Post-mitigation plan

The post-mitigation stage cumulative distribution histogram for the entire work is shown in Figure 22. Following the mitigation response steps, this histogram represents the outcome of the post-mitigation scenario. There is a 2% probability of completing the project on May 20, 2018. The likelihood of completing the entire project by June 5, 2018, is 50%, while there's an 80% chance of completion by June 16, 2018. Figure 22.A demonstrates that a 27-day time contingency reserve is necessary to achieve an 80% confidence level in project completion. The project cost histogram at project completion is shown in Figure 22.B. 24,686,726 SAR was the deterministic cost. The histogram shows that this cost could be used to complete the project with a probability of less than 1% for the entire set of works. With a 50% chance, the total project completion cost might come to 25,359,247 SAR. With an 80% chance of success, the total project completion cost might be 25,635,617 SAR. To achieve an 80% confidence level in project cost, an additional cost contingency reserve of 948,891 SAR was required.

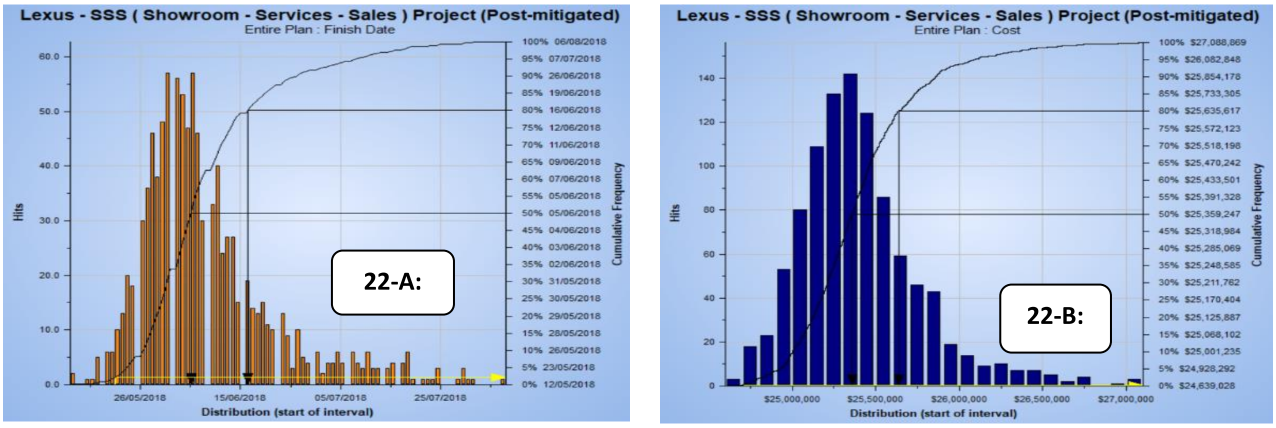


Figure 22 Post-mitigation plan distribution histogram for finish date and cost

6.13.3. Reviewing the response plan

The distribution analyzer is a very useful tool in Primavera Risk Analysis. It allows the project manager to decide and approve the mitigation actions and the contingency reserve for the project by using the data for the original plan, pre-mitigation plan, and post mitigation plan for both duration and cost. The differences in costs and durations between the original plan and the post-mitigation plan are shown in Figures 23 and 24.

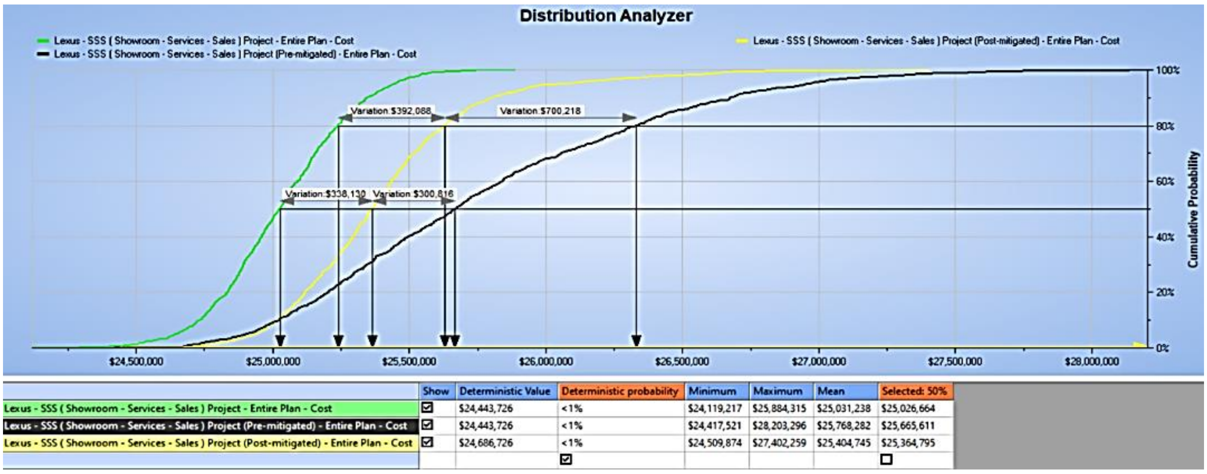


Figure 23 Distribution analyzer for cost

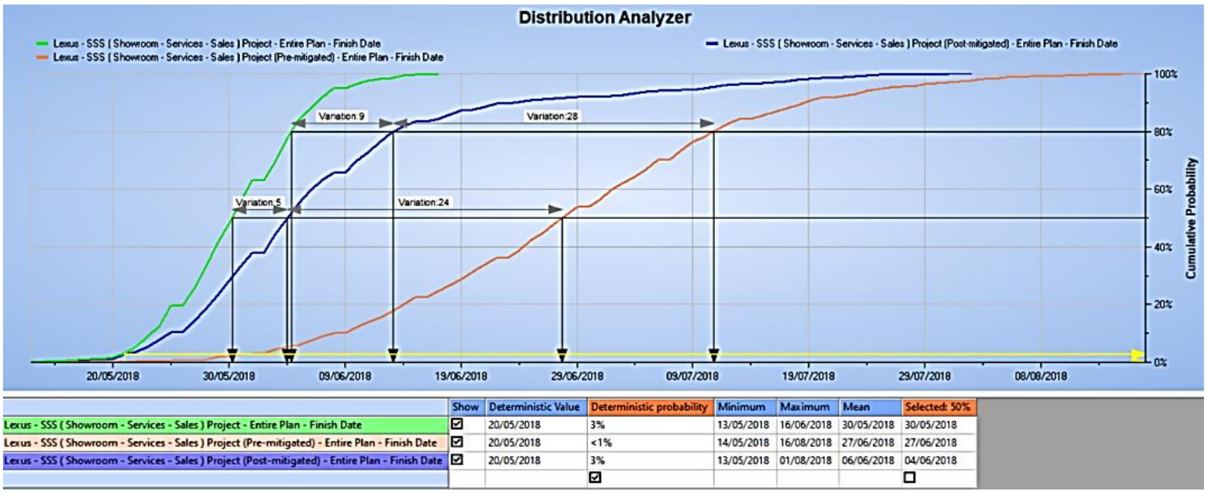


Figure 24 Distribution analyzer for finish date

6.14. Building Information Modeling by Autodesk Revit & Navisworks

6.14.1. Creating project 3d model: Architectural and structural design

The architectural and structural models were created using Autodesk Revit. The project was divided into four parts: architecture, structure, mechanical, and electrical. Each one of them was modeled in a separate file, and the architectural model was linked to the other models to enhance collaboration and optimize coordination between models, as shown in Figure 25.

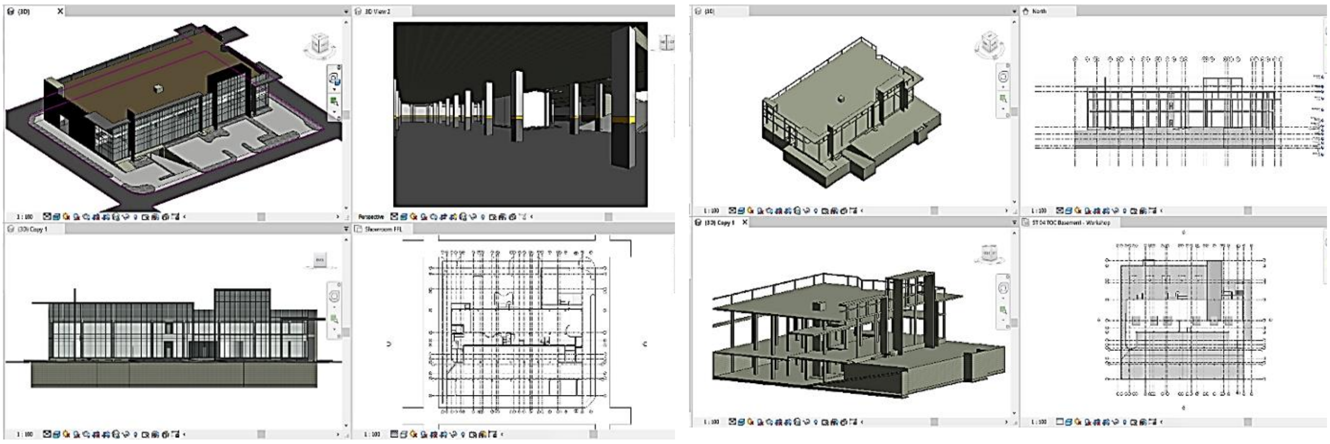


Figure 25 Autodesk Revit model; architectural and structural models.

6.14.2. Building electromechanical design

An amalgamation of many disciplines needed to manage the project once it is constructed is the electromechanical model. Among the primary disciplines involved in the construction of electromechanical models are mechanical, electrical, firefighting, and plumping. As seen in the image (26), an MEP BIM model was created for the project using Revit.

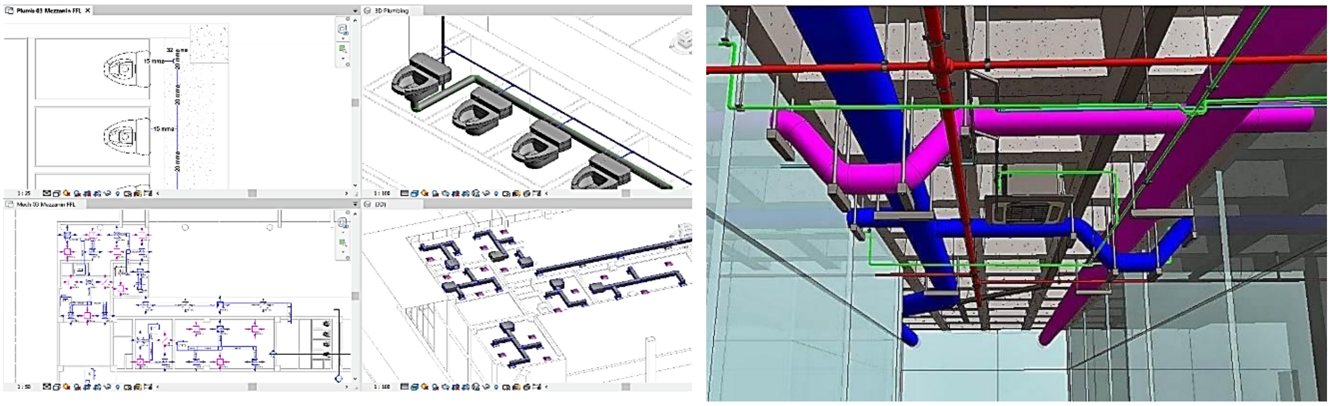


Figure 26 Autodesk Revit MEP model

The model was created and used as a communication tool to reduce the time needed to review and approve the submittals, and throughout these processes, RISK4 and RISK5, which relate to the review cycle, were mitigated to the minimum level.

6.14.3. Coordination between discipline and resolution: Model integration to create BIM

Autodesk Navisworks was used to create the integrated BIM model after importing all the models from Autodesk Revit. The purpose of the model's development was to examine conflicts between disciplines, cost and quantity computations, and 4D construction simulations. As seen in Figure 27, the model made on Navisworks can be utilized as a communication tool within the project during the construction stage.

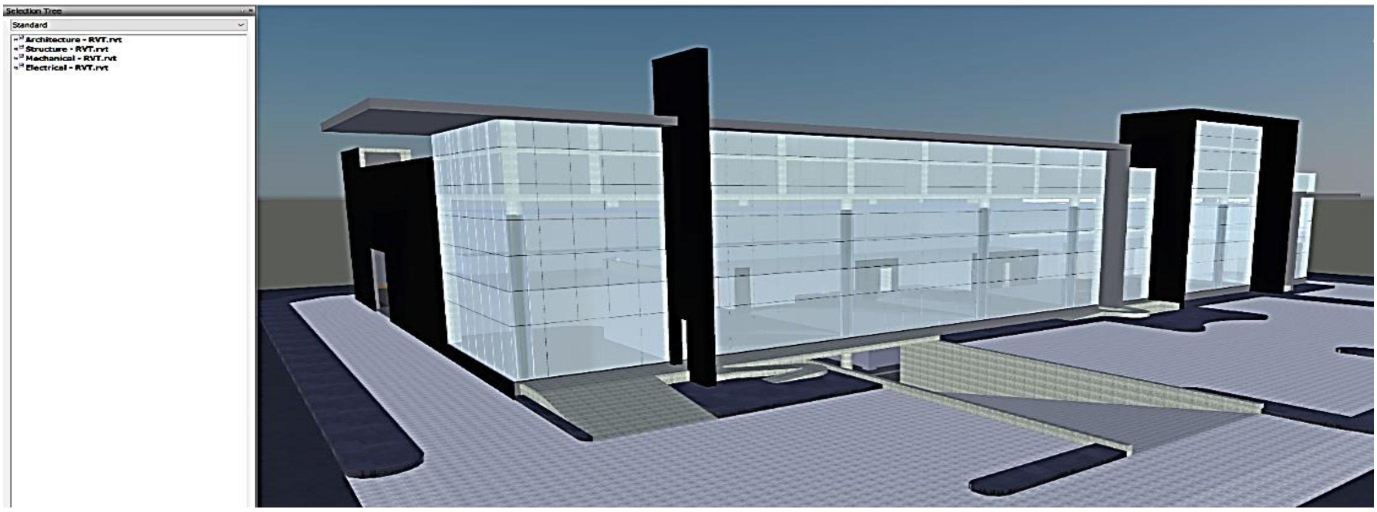


Figure 27 Autodesk Navisworks model

6.14.4. Clash detection and drawing review

Autodesk Navisworks was employed to identify clashes within the integrated models and generate clash detection reports, facilitating resolution by the responsible parties. This tool was used to reduce the RISK6 in the project by checking the coordination between the different disciplines drawings, as shown in Figure 28.

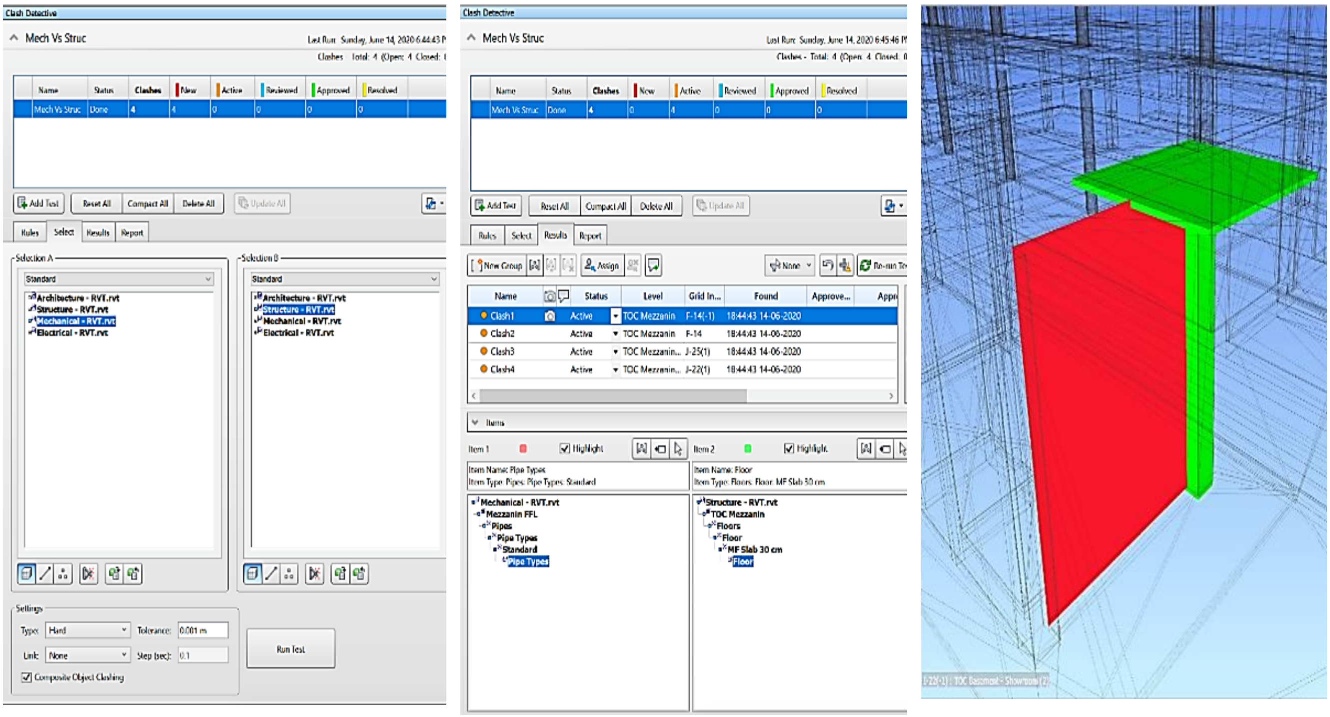


Figure 28 Autodesk Navisworks clash detective tool

All clashes in the model were solved early in the project, and this helped mitigate the risks in the design phase.

6.14.5. 4D modeling (construction simulations)

Autodesk Navisworks was used to create a 4D construction simulation from an integrated BIM model by integrating the construction time schedule developed in Primavera P6 or any similar software with the integrated model, as shown in Figure 29.

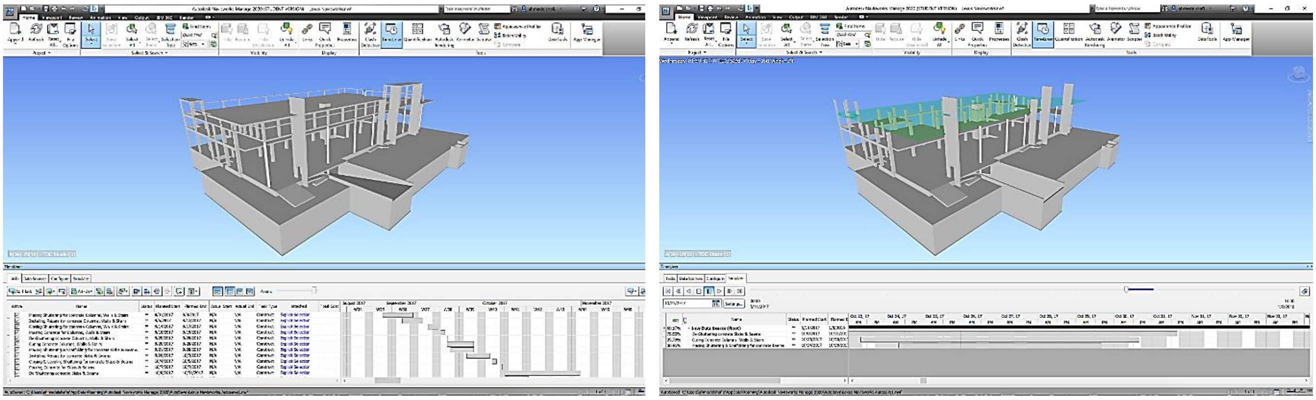


Figure 29 Autodesk Navisworks timeliner tool and time simulation.

Timeliner tools were used, and the schedule from the Primavera P6 was inserted into the data sources. From the refresh option, the tasks were created by the rebuild task hierarchy option. Every element was attached to the task of the time schedule to build the 4D time model, which helped the project management team test the construction procedures and the logic of the time schedule. The risks in the project were reduced.

6.14.6. 5D modeling: Assigning costs to model

Project parameters were created and assigned to the model's various categories to facilitate accurate budget estimation by inputting detailed cost information. All cost estimation data for each model element was incorporated into these project parameters. One of the major risks in the project was RISK-8 (inaccurate quantities) and RISK-9 (lack of consistency between bills of quantities, drawings, and specifications). To mitigate these risks, the cost of each element was integrated with the quantities as shown in Figure 30.

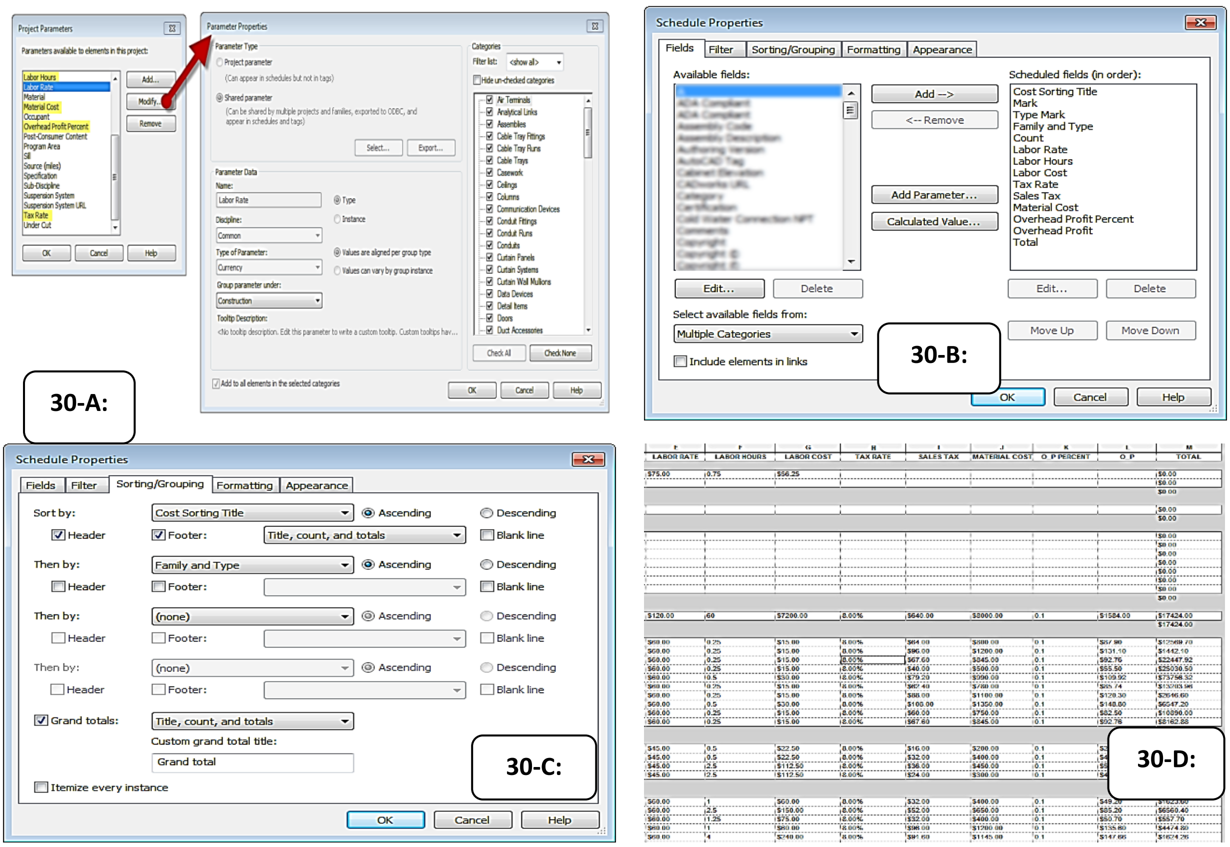


Figure 30 Autodesk Revit A. project parameters, B. schedule properties, D. schedule output

6.14.7. Create BOQ with quantification tool

The area book, building book, and room book tools collectively provide comprehensive capabilities for precise area and quantity calculations within Revit projects. These extensions assist users in configuring surfaces, areas, and volumes in accordance with national and international standards (International and DIN/VOB), in addition to automating the detection of these elements. The tools provide precise model take-offs, from which results could be exported to Microsoft Excel. In order to provide a complete material quantification that considers layers, pieces, and components, the Building-Book Extension calculated the material-related quantities of constructive building parts. With the help of this tool, the project's complete bill of goods was created, ensuring the best possible correlation between the drawing set of the model that was used to minimize the RISK-8 and RISK-9 in the project, as shown in Figure 31.

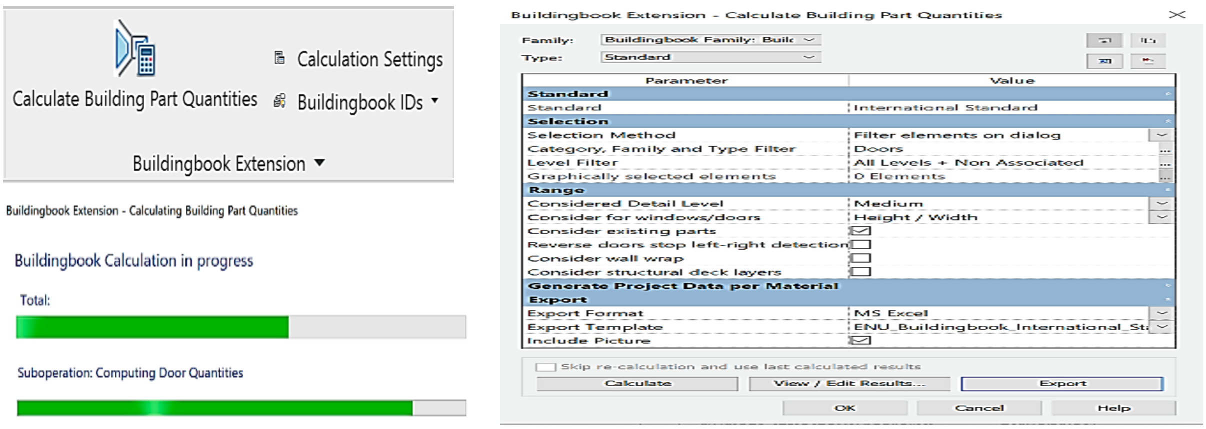


Figure 31 Autodesk Revit building book tool

All the data was exported to Microsoft Excel software, as spreadsheets contained all the required data from the model to be a part of the tendering documents after finishing the design stage of the project. The data encompassed comprehensive information about each element, including quantity, materials, dimensions, area, volume, and additional relevant details as required.

7.0 CONCLUSION

All construction projects face risks, and mitigating these risks is an important attempt to achieve the project's objectives, such as cost, time, and quality. The paper focused on two important risks that have a high probability of impacting the project during its life cycle. These risks involve coordination between different disciplines and communication between different stakeholders. Based on the analysis of the data, using BIM early in the project life cycle can reduce project risks by developing the model, detecting conflicts, and establishing discipline-wide coordination, which gives the go-ahead for the construction phase. Additionally, the BIM model is an efficient tool for information distribution, ensuring that updated data and any changes are distributed perfectly between project parties. These can help reduce or eliminate project risks, which can improve the project's ability to achieve its goals. While numerous studies support the use of BIM in construction management, few of them provide guidance on how to utilize BIM correctly; hence, this study focused on implementing BXP to get the correct implementation of BIM and avoid the second set of risks.

NOTATIONS

3D,4D	Three Dimensions Model, Four Dimensions Model (Model with Additional Time Information)
5D	Five Dimensions Model (Model with Additional Cost Information)
AEC	Architecture/Engineer/Construction
BIM	Building Information Modeling
BXP	BIM Execution Plane
CAD	Computer-Aided Design
FM	Facilities Management
NIBS	The National Institute of Building Sciences

O&M	Operations and Maintenance
RM	Risk Management
SPSS	Statistical Package for Social Science (Software)

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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