PROJECT COST RISK MANAGEMENT USING BUILDING INFORMATION MODELLING

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ABSTRACT

Due to their similar positive and negative effects on all project participants, cost and time are the two leading indicators of project success in construction. Completing projects within budget is an indicator of efficiency, but there are many unpredictable factors that can arise during the construction process and affect the efficiency. Often, projects fail to keep up with the budgeted costs and planned schedules to meet their objectives. From the planning stage to project completion, numerous known and unknown risks significantly impact construction costs. To address these risks, numerous theories and models have been put forth. However, the consistent cost overrun on most projects demands more work on its resolution. Building information modelling (BIM) is touted as a potential remedy for issues facing the construction sector due to its capabilities in the designing phase, planning and scheduling and enhancement of communication and collaboration among project participants. However, the effect of BIM on cost overrun has not been sufficiently studied so far. This study focuses on project cost risk management using the modern concept of BIM. In doing so, significant risks affecting project cost will be identified, along with the features of BIM that help solve these risks. Based on the feature-factor matrix, the resolution capacity of identified risks due to BIM will be assessed and applied through case studies, and the pre and post-BIM risk levels will be determined through a fuzzy logic model. The implications of this research involve value assessment of BIM in resolving cost-related risks that will help stakeholders achieve project success and promote BIM adoption to its fullest.

KEYWORDS

Cost Overrun, Risks, BIM, Fuzzy Logic

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CHAPTER 1

INTRODUCTION

1.1 Background

The two primary indices of project success in construction are time and cost, which have an equal positive and negative impact on each project stakeholder (Johnson et al., 2018). Completing projects on time and within budget indicates efficiency, but the construction process is fraught with variables and dubious factors that emerge from various sources, thus negatively affecting efficiency. Cost overruns are becoming more prevalent in the construction industry, ranging from straightforward to complex projects like oil and gas platforms, nuclear power plants, environmental restoration, and transportation systems (Baloi & Price, 2003). From the initial stages of estimation to project completion, several factors significantly impact construction costs. Cost overruns have an impact not only on the construction industry but also on the overall economy. A number of factors, including inadequate planning and scheduling by contractors, delays in material procurement, shortages of materials, poor technical performance, and scope variations, can influence a project's construction costs. (Memon et al., 2010).

Construction project risk management has become a difficult task, which can be attributed to problems like the complex nature of current projects (Maseko, 2018). A Risk management process starts with the identification of project risks. After that, these risks are analyzed and then actions are determined to avert the threats on any project. All risk management process steps must be included in the project's implementation to deal with risks (Mhetre et al., 2016). An effective risk management strategy can help us understand the different risks we may face and how to handle them throughout the different project phases. Due to its growing significance, risk management is now acknowledged as a crucial subject in most industries, and several methods have been developed to limit potential risks' effects (Schulyer, 2000).

Because it can store all the data related to a facility, Building information modeling (BIM), described as "digital representation of physical and functional characteristics of a facility" (NBS International BIM Report 2013) is seen as a promising solution to problems in the Architecture, Engineering, and Construction (AEC) sector. This establishes the framework on which the BIM tools carry out a range of analyses, including structural analysis (Weygant, 2011) and promotes information exchanges and software application interoperability throughout the project lifecycle (Howard & Björk, 2008), which increases productivity and improves teamwork and communication among project participants. BIM significantly enhances the design phase because it allows for in-depth analysis, simulations, and the viability of alternative designs (Azhar, 2011).

A substantial amount of research has been carried out in identifying the perceived benefits of Building Information Modeling in all aspects of the project. However, traditional drawings and methods are still heavily utilized by the AEC sector in developing nations to conduct business. On the other hand, Building Information Modeling (BIM) has brought about one of the construction industry's latest advancements and fundamental changes has led to deeper project stakeholders' coordination. One of the newest advancements in the construction industry, BIM, helps projects solve problems more quickly. Architects, engineers, contractors, project managers, and other professionals can use BIM to accomplish goals like lowering design errors, cutting costs and time, enhancing design and construction integration, and improving coordination and cooperation between various sections (Samimpay & Saghatforoush, 2020). In this regard, there is very less published data, which serve the need of our construction sector in realizing the benefits of Building Information Modeling and using it as a risk management tool. Because BIM can present many opportunities, lower design uncertainty and improve coordination among project stakeholders, it has been asserted that "a detailed BIM model is a risk mitigation tool." (Eastman et al., 2011, Deutsch, 2011).

BIM's one of the most significant advantages is decrease in construction costs. Based on case studies carried out, BIM implementation had the most significant positive impact on cost, followed by time, communication, better coordination, and quality (Bryde et al., 2013). However, how can BIM address the risks, which negatively affect our construction costs, is not an area explored? Therefore, this research seeks to close this gap by identifying BIM features that mitigate cost risks with the help of interviews based on five case study projects and provide easy to use guidelines for proper risk transformation using the Building Information Modeling. The case studies uses fuzzy logic tool to quantify risk levels before and after using BIM.

1.2 Research Problem

Construction industry has a dismal reputation in terms of completing projects on budget. Cost overruns typically occur in nine out of ten projects. Previous research have already identified many factors contributing to project cost overruns (Aljohani, 2017). As, risk factors that result in cost overrun have been identified through many studies, similarly studies have been documented on mitigation of these risks. For example, (Bouayed, 2016) demonstrated that Monte Carlo simulation can assist project managers in mitigating the risk of project cost overruns, and (Annamalaisami & Kuppuswamy, 2021) developed a taxonomy to mitigate cost risk factors. Similarly, (Tahir et al., 2018) argued that the primary causes of cost overruns, such as inaccurate estimations, clashes, integration issues, and many others, are addressed by BIM. (Sami Ur Rehman et al., 2020a) identified BIM features that address schedule risks and validated a feature-factor matrix through survey while the same work for cost risk is needed to be carried out.

1.3 Previous Studies

The construction sector is complicated and fragmented worldwide (Mohd Nawi et al., 2014). The environment in which construction industry operates is very risky because of each project's fragmented and distinct nature. The unique characteristics of building projects, such as extended time, complex procedures, a deplorable climate, financial intensity, and dynamic organizational structures, has subjected the construction sector to more significant risks than many other industries (Ganame & Chaudhari, 2015).

BIM refers to all the operations involved in creating, maintaining, utilizing, and modifying a facility’s digital representation. Building information models is the term for these digital representations, which include functional geometric and elements (König et al., 2012). In order to support planning, construction, management, utilization, revitalization, and deconstruction activities, building information models are frequently used as shared knowledge and data resources (Eastman et al., 2011). Building Information Modeling reduces the cost of construction or prevent the project from cost overrun through its coordination, clash detection, 3D modeling and other capabilities but a specific framework is yet to be developed. In general, BIM models are not used to their full potential. Model objects frequently lack the essential information needed for project cost managers and other construction industry professionals to benefit from the model entirely (Smith, 2015).

Similarly, much research is carried out on the project cost's risk factors. Through survey-based research, high inflation/ increased cost, problematic design, change in design by the owner, delayed payments and faulty construction work was perceived as the most critical risk factors in descending order in terms of project cost (Scott et al., 2005). A recent study addressed the project schedule risks using BIM. The study examined how BIM can help identify schedule risks and offer a practical schedule management solution. It was found that BIM substantially impacts the schedule management of construction projects (Sami Ur Rehman et al., 2020a).

After an extensive literature review, not much published data is available that integrates the critical risks which affect project cost with Building Information Modeling. After successfully identifying key risk factors that affect the construction project cost, the Building Information Modeling tool will be implemented. After having its output, basic guidelines for the critical management of construction projects will be formulated. This study will help and guide the project management in implementing the Building Information Modeling tool on their projects while getting the maximum benefit.

1.4 Research Question

Following research questions has directed this research.

1. Does BIM mitigate the risks that causes cost overrun?
2. How much the risk level is decreased by using BIM?

1.5 Research Objectives

i. Identifying key risks that affect the cost performance during the whole construction process.
ii. To develop a Feature - Factor matrix that identifies the potential relationship between BIM features and cost risk factors.
iii. To validate the proposed matrix and quantify the benefits of BIM through interviews from stakeholders of different projects using fuzzy logic model.

1.6 Reasons / Justification for Selection of the Topic:

A country's primary industry, the construction sector, consumes most of its resources. Minimizing the uncertainties associated with construction projects and improving the efficiency of construction processes will result in country-level benefits, especially in public projects. Clients always want their projects to be completed within desired budgets and allocated time. The client and the general public can use the facility for its intended purpose if the project is finished on schedule and within budget. However, when projects run over their targeted cost, it causes damage to both the constructor and client in terms of profit loss. Thus, this topic was selected after carrying out sufficient related studies to help the industry achieve its set objectives.

1.7 Relevance to National Needs

Modern tools like Building Information Modeling add value to management aspects of the construction industry. Pakistan’s construction industry is still working on traditional construction management approaches, and the research of our institutions related to the latest technologies and ICT is in its early stages. Identification of cost risks and then investigating their solution through BIM integration helps us understand its benefits for the cost management during life cycle of the project. Therefore, to evade the construction cost overruns, this study will prove an effective effort towards resolving the cost issues, which occur in the traditional project management techniques by using the concept of Building Information Modeling.

1.8 Advantages

i. Key Risk Factors will be identified which can be helpful for Project Management to implement BIM into their projects.
ii. After using BIM into real life projects, better understanding of its usefulness will be achieved.
iii. Established guidelines will help key management to implement BIM tool on their projects with much more confidence.
iv. Project Managers will have more control over the cost tracking over the life cycle of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

This chapter examines earlier work that is related to our research. It includes discussing how to effectively control costs, issues with construction project costs that cause cost overruns, and potential solutions using modern tools and techniques. This chapter also advances our understanding of building information modeling and its application in identifying and resolving cost-related risks by connecting pertinent research literature.

The cost of a project is one of the most important criteria to determine its success. The situation where the actual cost exceeds the initial estimate is known as a cost overrun (Invernizzi et al., 2017). People involved in the construction industry are often criticized for cost overruns, especially on publicly funded infrastructure projects of greater importance. The most problematic disputes in construction projects are often because of cost overrun and not being able to complete the work within the designated budget (Alghonamy, 2015).

A construction project is undertaken when it is economically justified but the cost overrun lose this justification (Stasiak-betlejewska & Potkány, 2015). Therefore, controlling project cost is necessary throughout the project life cycle. A practical and sound cost management and control technique is essential for minimizing cost overruns' risk of a construction project. Due to the growing involvement of different stakeholder from various disciplines, construction projects are turning out to be more complex. But now, due to the development of different technologies like Building Information Model (BIM), it is believed that problems related to project cost will be resolved to a greater extent because of their efficient nature to increase collaboration between stakeholders (Tahir et al., 2018).

2.2 Construction Project Cost Overrun

There has always been criticism over the construction industry for not completing projects within the budgeted cost. Generally, 90% of the projects face cost overrun. Construction projects that exceed the designated cost limit have the potential to become defaulted projects, resultantly affecting all the projects' parties. Channel Tunnel project is one of the famous example of cost overrun (Aljohani, 2017).

It is necessary to clarify a debate that is going on in existing literature between two separate but related issues i.e. cost overrun and cost underestimation. Many of the cost models have become shortsighted because of the absence of this distinction. Due to the uncertainty and unavailability of detailed information, the initial cost estimations are often inconsiderate and underestimated. Contrary to this, overruns are defined as the cost difference at project completion and project definition stage (Ahiaga-dagbui & Smith, 2014).

Cost overrun is not always about money. Although it has different impacts on different stakeholders, it is assertive that everyone involved is affected and the effects pass to the national economy. The primary sufferer is mostly the project owner as he is the one to initiate the project, allocate the budget, and forecast the timeframe. Moreover, project duration is directly impacted by cost overrun. Cost overrun delay the projects and will further increase the project cost due to inflations and interest accumulation (Nega, 2008).

2.2.1 Controlling Cost Overrun

Finding cost-controlling strategies and their effects on reducing cost overruns is crucial. Generally, contractors know most of the cost control techniques known to the construction industry, but their proper implementation is minimal. Many contractors concur that the two most important tools for cost management are Microsoft Project and Earn Value Analysis. (Malkanthi et al., 2016).

Moreover, effective mitigation measures include avoiding frequent design changes, effective procurement systems, following schedule, proper system of site management and supervision, hiring competent labor etc. (Roslan et al., 2014). Within construction projects, introducing an efficient resource (human, technical, and material) management system is one potential solution to lessen the impact of cost overrun in projects, as most of the causes of cost overrun are related to poor resource management (Aljohani, 2017). Other measures include timely payment to contractors, proper planning and cost estimation, avoiding unnecessary interference, removing communication gap and awarding contracts on merit (Sohu et al., 2018).

2.2.2 Causes of Cost Overrun

Aljohani et al., (2017) carried out a study and discovered more than 170 causes of cost overruns in seventeen contexts, the most significant of which were: repeated changes in design, financially weak contractor, delayed payment for finished work, contractor’s inexperience, inaccurate cost estimation, improper tendering documentation, and poor site management including material. Another research carried out on UAE construction industry, (Johnson et al., 2018) concluded that the top five reasons for cost overrun include change orders from clients, design modifications from clients and consultants, unrealistic time estimates made by clients and consultants, as well as delays in getting government permits and approvals, are all common problems. Moreover, according to the work done by (Doloi, 2013), from clients, consultants, and contractors’ perspectives, planning and scheduling flaws significantly impact cost performance when the relative importance weighting technique was applied to 48 selected attributes. Other factors influencing cost overrun are, poor and inaccurate construction documentations, lack of communication between client and contractor, complexity of design etc.

2.3 Project Cost Risks

Risk is commonly defined as a scenario in which loss or unfavorable circumstances may occur; it is not inevitable and is based on various sources and uncertainties. An application of Murphy's Law (What may go wrong, will go wrong) is a more simplified illustration of risk; in other words, most people only view risk as a possibility for adverse consequences, but it might just as quickly be a chance for improvement (Wang & Chou, 2003).

In the current study, risk factors were identified through extensive literature review. Thirty studies, published during the years 2000-2019, were consulted to list down the risk factors because of which projects' cost overrun. Poor and inflexible design (Johnson et al., 2018; Memon et al. 2011), poor cost and time estimation (Enshassi et al., 2017; Famiyeh et al., 2017), delay in client's decision making process (Bekker et al., 2016; Mulla et al., 2015), poor initial planning & scheduling (Alghonamy, 2015; Bahamid et al., 2019), unforeseen ground and weather conditions (Odediran et al., 2012; Ramabodu & Verster, 2013) poorly defined scope and change in scope (Rahman et al., 2013; Wakjira et al., 2011), unavailability of skilled and unskilled labor (Al-Juwairah, 1997; Ameh et al., 2010) were some of the most significant risk factors impacting cost.

List of risk factors, which affects cost performance, identified from extensive literature review, are given in Table 2-1.

Table 2.1: List of Key Risk Factors

Sr. #	**Risk Factor**	**Description**	**Source(s)**
1	Poor and incomplete design	*Design* is the systematic road map that leads to the goal of any project. Poor and incomplete design issue could lead to poor project performance and cost overrun.	(Al-najjar 2008; Alghonamy 2015; Azis et al. 2013; Bahamid 2019; Bekr 2015; Doloi 2013; Enshassi 2017; Famiyeh et al. 2017; Memon et al. 2011; Mulla and Waghmare 2015; Nega 2008; Odediran, Adeyinka, and Eghenure 2012; ; Rahman, Memon, and Karim 2013; Ramabodu and Verster 2013; Scott 2005; Shanmugapriya and Subramanian 2013)

Sr. #	Risk Factor	Description	Source(s)
2	Delays and changes in design	Frequent changes and delays in design could happen due to various reasons. These changes cause delays in the schedule, particularly if they require additional work or rework. Resultantly, the cost of project will rise.	(Abbas and Painting 2017; Al-Juwairah 1997; Al-najjar 2008; Alghonamy 2015; Ameh, Soyingbe, and Odusami 2010; Azis et al. 2013; Bahamid 2019; Bekr 2015; Doloi 2013; Durdyev 2012; Enshassi 2017; Johnson, Itty, and Babu 2018; Memon et al. 2010, 2011; Mulla and Waghmare 2015; Nega 2008; Odediran, Adeyinka, and Eghenure 2012; Rahman, Memon, and Karim 2013; Scott 2005; Wakjira 2011; Polat, Okay, and Eray 2014)
3	Poor and Inaccurate cost estimation of the project	Construction projects suffer from inaccurate cost estimation. Cost overestimation can result in the owner spending more than necessary for the project or leading them to decide not to move on, while cost underestimation might have the opposite effect.	(Al-Juwairah, 1997; Ameh et al., 2010; Bahamid et al., 2019; Bekker & Lucius, 2011; Bekr, 2015; Durdyev et al., 2010, 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Memon et al., 2011; Mulla & Waghmare, 2015; Nega, 2008; Odediran et al., 2012; Polat et al., 2014; Rahman et al., 2013; Shiferaw Belachew et al., 2017; Wakjira, 2011)

Sr. #	Risk Factor	Description	Source(s)
4	Poor and Inaccurate time estimation of the project	The main factor that further contributes to cost overrun is time overrun. The deviation from the initially agreed-upon time and cost determines whether any work will be completed, and failure to comply with this will result in project delays and cost overruns.	(Al-Juwairah, 1997; Bekr, 2015; Famiyeh et al., 2017; Johnson et al., 2018; Memon et al., 2010, 2011; Mulla & Waghmare, 2015; Rahman et al., 2013; Shiferaw Belachew et al., 2017)
6	Financial constraints of client	Payment delays to contractors are the result of owner financial difficulties. As a result, contractors' cash flow is impacted, slowing the project's advancement.	(Al-Juwairah, 1997; Al-najjar, 2008; Azis et al., 2013; Bahamid et al., 2019; Durdyev et al., 2017; Famiyeh et al., 2017; Johnson et al., 2018; Memon et al., 2011; Mulla & Waghmare, 2015; Naveenkumar & Prabhu, 2016; Nega, 2008; Polat et al., 2014; Rahman et al., 2013)
7	Delay in client's decision-making process or issuing instructions	The decision-making process of the client can hold up site work and progress. The client is in charge of making sure that everyone involved in the project is aware of its goals and requirements.	(Abbas & Painting, 2017; Al-najjar, 2008; Bekker & Lucius, 2011; Doloi, 2013; Durdyev et al., 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Johnson et al., 2018; Memon et al., 2010, 2011; Mulla & Waghmare, 2015; Naveenkumar & Prabhu, 2016; Nega, 2008; Polat et al., 2014; Rahman et al., 2013; Shiferaw Belachew et al., 2017; Wakjira, 2011)

Sr. #	**Risk Factor**	**Description**	**Source(s)**
8	Contractor's resource deficiency/ Financial problems	The most important factor during execution of a project is budget and resources. Successful project relies on timely financing from contractor's end. Regular payments to labor, material suppliers and sub-contractors is vital for successful cost performance.	(Abbas & Painting, 2017; Al-Juwairah, 1997; Azis et al., 2013; Bahamid et al., 2019; Doloi, 2013; Durdyev et al., 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Johnson et al., 2018; Memon et al., 2011, 2010; Nega, 2008; Polat et al., 2014; Rahman et al., 2013)
9	Lack of contractor's experience	Cost, experience, and reputation are taken into consideration when choosing contractors. Price, experience, and reputation are typically trade-offs, but choosing the lowest bid does not always result in a project that is finished on time and within budget.	(Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010; Bahamid et al., 2019; Doloi, 2013; Enshassi et al., 2009; Johnson et al., 2018; Kaming et al., 1997; Memon et al., 2011, 2010; Mulla & Waghmare, 2015; Naveenkumar & Prabhu, 2016; Nega, 2008; Rahman et al., 2013)

Sr. #	**Risk Factor**	**Description**	**Source(s)**
10	Poor initial planning & scheduling	The success of construction projects depends greatly on scheduling and planning, as good planning will gather the necessary resources to complete the project's goals within the allotted time, budget, and quality constraints.	(Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010; Bahamid et al., 2019; Bekr, 2015; Doloi, 2013; Durdyev et al., 2010; Enshassi et al., 2009; Johnson et al., 2018; Memon et al., 2010, 2011; Mulla & Waghmare, 2015; Nega, 2008; Odediran et al., 2012; Polat et al., 2014; Rahman et al., 2013; Scott et al., 2005; Shiferaw Belachew et al., 2017; Wakjira, 2011)
12	Lack of risk management	Risk in the construction creates the possibility of financial loss due to unforeseen circumstances. Effective risk management is crucial for preventing project cost overruns.	(Johnson et al., 2018; Odediran et al., 2012)
13	Size and complexity of the project	The scope of the project can serve as a measure of complexity. Compared to small projects, most mega projects have a longer implementation period. Due to this, it might be necessary to supplement the initial budget in order to finish the project.	(Bahamid et al., 2019; Bekker & Lucius, 2011; Doloi, 2013; Johnson et al., 2018; Memon et al., 2011; Nega, 2008; Odediran et al., 2012; Shiferaw Belachew et al., 2017)
14	Unfavorable site and weather conditions		(Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010;

Sr. #	**Risk Factor**	**Description**	**Source(s)**
		Unexpected subsurface conditions may occasionally necessitate a costly, fundamental redesign of projects. Additionally, unfavorable weather results in unneeded delays and costs more money.	Bahamid et al., 2019; Doloi, 2013; Durdyev et al., 2010, 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Johnson et al., 2018; Kaming et al., 1997; Memon et al., 2010; Mulla & Waghmare, 2015; Nega, 2008; Odediran et al., 2012; Polat et al., 2014; Ramabodu & Verster, 2013; Scott et al., 2005; Shiferaw Belachew et al., 2017; Wakjira, 2011)

Sr. #	Risk Factor	Description	Source(s)
15	Inflation and fluctuation of material and machine prices	An increase in an economy's overall price level is known as inflation. The cost of construction may rise as a result of inflation. The original cost estimate will be exceeded if the inflation rate rises during the construction period above the anticipated level.	(Abbas & Painting, 2017; Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010; Azis et al., 2013; Bahamid et al., 2019; Bekker & Lucius, 2011; Bekr, 2015; Doloi, 2013; Durdyev et al., 2010, 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Johnson et al., 2018; Kaming et al., 1997; Memon et al., 2010; Mulla & Waghmare, 2015; Nega, 2008; Odediran et al., 2012; Polat et al., 2014; Rahman et al., 2013; Scott et al., 2005; Shanmugapriya & Subramanian, 2013; Shiferaw Belachew et al., 2017; Wakjira, 2011)
16	Unrealistic contract duration and requirements imposed	Reasonable duration from owner and contractor as well is vital. Sometimes due to various reasons client/owner sets very unrealistic durations which effects the project.	(Al-Juwairah, 1997; Alghonamy, 2015; Ameh et al., 2010; Bahamid et al., 2019; Durdyev et al., 2010, 2017; Famiyeh et al., 2017; Johnson et al., 2018; Memon et al., 2011; Naveenkumar & Prabhu, 2016; Polat et al., 2014; Shiferaw Belachew et al., 2017; Wakjira, 2011)

Sr. #	**Risk Factor**	**Description**	**Source(s)**
18	Poor site management and supervision	Improved site management is essential for lowering cost overruns because it significantly influences productivity. The contractor's site management affects the project's overall progress.	(Al-najjar, 2008; Ameh et al., 2010; Azis et al., 2013; Bahamid et al., 2019; Doloi, 2013; Durdyev et al., 2010, 2017; Famiyeh et al., 2017; Johnson et al., 2018; Memon et al., 2011, 2010; Mulla & Waghmare, 2015; Naveenkumar & Prabhu, 2016; Rahman et al., 2013; Wakjira, 2011)
19	Inaccurate quantity take-off	Estimating materials is referred to as quantity takeoff. It requires skill, endurance, keen observational abilities, and much experience. It is critical to executing takeoffs correctly due to the amount of money and people involved.	(Al-najjar, 2008; Bekker & Lucius, 2011; Enshassi et al., 2009; Kaming et al., 1997; Memon et al., 2011; Nega, 2008; Odediran et al., 2012; Rahman et al., 2013; Shiferaw Belachew et al., 2017)
20	Poor project management	Application of knowledge, expertise, techniques, and methodologies to satisfy project requirements is emphasised in project management. Its role begins with the project's feasibility study and continues through project commissioning.	(Azis et al., 2013; Bahamid et al., 2019; Durdyev et al., 2017; Famiyeh et al., 2017; Memon et al., 2011; Rahman et al., 2013; Wakjira, 2011)

Sr. #	**Risk Factor**	**Description**	**Source(s)**
21	Incomplete drawings and project details	The start of the project will be delayed and project will cost overrun due to incomplete drawings and documents. The same could be caused by a delay in the release of fully completed drawings and contractual documents before execution.	(Al-najjar, 2008; Azis et al., 2013; Bahamid et al., 2019; Bekr, 2015; Doloi, 2013; Enshassi et al., 2009; Johnson et al., 2018; Memon et al., 2011; Mulla & Waghmare, 2015; Odediran et al., 2012; Rahman et al., 2013; Ramabodu & Verster, 2013; Scott et al., 2005)
22	Communication/Coordination problems between parties	All of the project's key players must adequately coordinate. Many issues arise during project execution that requires the client, consultants, and contractors' input. All parties must regularly coordinate throughout the project's lifespan.	(Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010; Azis et al., 2013; Bahamid et al., 2019; Doloi, 2013; Durdyev et al., 2010, 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Memon et al., 2010, 2011; Mulla & Waghmare, 2015; Nega, 2008; Odediran et al., 2012; Rahman et al., 2013; Shanmugapriya & Subramanian, 2013; Shiferaw Belachew et al., 2017; Wakjira, 2011)

Sr. #	Risk Factor	Description	Source(s)
23	Mistakes and discrepancies in construction documentations	Any inconsistency among the documents will result in a delay. Sometimes, the project drawings do not match the technical specifications or the bill of quantities, which leads to confusion when the contractor is implementing their work and may result in conflicts between the supervisor team and the contractor, which would delay the project.	(Al-najjar, 2008; Azis et al., 2013; Bahamid et al., 2019; Doloi, 2013; Enshassi et al., 2009; Famiyeh et al., 2017; Mulla & Waghmare, 2015; Nega, 2008; Ramabodu & Verster, 2013; Shiferaw Belachew et al., 2017; Wakjira, 2011)
24	Client-initiated variations or Change orders	All kinds of construction projects frequently involve change orders. If not considered by all project participants, changes can be detrimental to any project and lead to cost overruns.	(Abbas & Painting, 2017; Al-Juwairah, 1997; Al-najjar, 2008; Bahamid et al., 2019; Bekker & Lucius, 2011; Bekr, 2015; Doloi, 2013; Durdyev et al., 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Johnson et al., 2018; Memon et al., 2010; Nega, 2008; Polat et al., 2014; Ramabodu & Verster, 2013; Shanmugapriya & Subramanian, 2013; Shiferaw Belachew et al., 2017; Wakjira, 2011)
25	Poor selection of contractors or Assigning contract to lowest bidder	Clients usually choose the lowest bidder to carry out their projects, and the lowest bidders might not be the best contractors. Poor cost performance could be a consequence of this.	(Abbas & Painting, 2017; Al-najjar, 2008; Alghonamy, 2015; Enshassi et al., 2009; Johnson et al., 2018; Memon et al., 2010; Wakjira, 2011)

Sr. #	Risk Factor	Description	Source(s)
26	Poor cost and financial control	It is challenging to manage the project's finances on the job site. Control of all resources is necessary, including labor productivity, material availability, material waste, excellent and efficient methods, efficient tools and equipment use, and effective project scheduling. All of these elements should be taken into account by project management to improve on-site financial control.	(Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010; Durdyev et al., 2017; Enshassi et al., 2009; Memon et al., 2011; Polat et al., 2014; Rahman et al., 2013; Ramabodu & Verster, 2013; Scott et al., 2005; Wakjira, 2011)
27	Unavailability of labor (skilled and unskilled)	No matter what type of the project is, availability of skilled workers is always important factor in project success. Availability of skilled labor at site for all activities accordingly are vital for the project.	(Al-Juwairah, 1997; Alghonamy, 2015; Ameh et al., 2010; Azis et al., 2013; Bahamid et al., 2019; Bekker & Lucius, 2011; Bekr, 2015; Durdyev et al., 2010, 2017; Johnson et al., 2018; Memon et al., 2010; Naveenkumar & Prabhu, 2016; Rahman et al., 2013; Scott et al., 2005; Shanmugapriya & Subramanian, 2013; Wakjira, 2011)

Sr. #	**Risk Factor**	**Description**	**Source(s)**
28	Poor contract administration	Managing contract is one of the crucial elements for a project's success. Administering a contract means managing all resources of a project and managing its content to avoid any dispute. Human knowledge and experience are some of the best indications of having good contract management.	(Al-Juwairah, 1997; Alghonamy, 2015; Ameh et al., 2010; Azis et al., 2013; Doloi, 2013; Famiyeh et al., 2017; Naveenkumar & Prabhu, 2016; Wakjira, 2011)
29	Inadequate specifications	A specification is a thorough explanation of how something was made, including plans and materials. A good specification should make the design goals, materials, thicknesses, finishes, and other specifications crystal clear. Inadequate specifications can result in rework and hence cost overrun.	(Bahamid et al., 2019; Nega, 2008; Odediran et al., 2012; Polat et al., 2014; Ramabodu & Verster, 2013; Shanmugapriya & Subramanian, 2013)

Sr. #	**Risk Factor**	**Description**	**Source(s)**
30	Poorly defined scope and change in scope	A poorly elaborated scope of project will almost certainly prevent a project from having a precise timeline and budget. To avoid issues with variations and changes in design throughout the project by clearly defining its scope. it is always necessary for the parties to get together before the project commences. This will help prevent time and cost overruns.	(Alghonamy, 2015; Ameh et al., 2010; Bahamid et al., 2019; Bekker & Lucius, 2011; Bekr, 2015; Durdyev et al., 2017; Enshassi et al., 2009; Famiyeh et al., 2017; Memon et al., 2010; Odediran et al., 2012; Polat et al., 2014; Rahman et al., 2013; Ramabodu & Verster, 2013; Shiferaw Belachew et al., 2017; Wakjira, 2011)
31	Location of site or Poor access	In densely populated areas, restricted access to construction sites is a significant problem that can harm the effectiveness of a project, especially in the early stages when materials must be moved into and around the work site, and there is a need for earthmoving work.	(Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010; Bahamid et al., 2019; Doloi, 2013; Durdyev et al., 2010; Enshassi et al., 2009; Kaming et al., 1997; Mulla & Waghmare, 2015; Naveenkumar & Prabhu, 2016; Odediran et al., 2012; Shiferaw Belachew et al., 2017)
32	Inadequate safety measures	Construction is full of hazardous activities. Each and every party engaged in the construction must take care of the safety of workers and equipment as well.	(Bahamid et al., 2019; Durdyev et al., 2010; Mulla & Waghmare, 2015; Polat et al., 2014)

Sr. #	Risk Factor	Description	Source(s)
33	Wastage on site	Waste is any loss caused by actions that produce direct or indirect costs but do not maximize the value of the final product. The cost overrun for a project would increase in direct proportion to any increase in material waste at the construction site.	(Al-Juwairah, 1997; Al-najjar, 2008; Ameh et al., 2010; Durdyev et al., 2010; Polat et al., 2014; Shanmugapriya & Subramanian, 2013; Wakjira, 2011)
34	Contractual Claims or Disputes	A claim is a request for compensation not anticipated in the original contract and arises at a later stage. Any modification to the initial contractual terms that has significant financial repercussions may give rise to disputes. Claims and disputes are the main hindrances in completing the project within objectives and goals.	(Al-Juwairah, 1997; Al-najjar, 2008; Alghonamy, 2015; Ameh et al., 2010; Bahamid et al., 2019; Bekr, 2015; Enshassi et al., 2009; Mulla & Waghmare, 2015; Rahman et al., 2013; Ramabodu & Verster, 2013; Wakjira, 2011)
35	Omissions and errors in BOQ	Bill of quantities (BOQ) is the major document that provides construction project stakeholders with initial cost estimates. Errors in BOQ contributes to poor cost performance with statistically significant effect size.	(Al-najjar, 2008; Enshassi et al., 2009; Ramabodu & Verster, 2013; Shiferaw Belachew et al., 2017)

Sr. #	Risk Factor	Description	Source(s)
36	Drawing changes and errors	Drawing errors and mistakes include incomplete drawings, omission of details, uncoordinated drawings, inconsistencies between drawn information and written information etc.	(Al-najjar, 2008; Enshassi et al., 2009; Ramabodu & Verster, 2013; Shiferaw Belachew et al., 2017)

2.4 Building Information Modeling (BIM)

BIM, a trendy term these days, is used by programmers and developers to describe the capabilities of their products and tools. As there is confusion in the definition of what is included in BIM technology, it is essential that models that do not use BIM tools be described. These models lack behavior support, require multiple 2D CAD reference files to define a building, allow changes to dimensions in one view but do not automatically update other views, only contain 3D data, and have few or no object attributes (Eastman et al. 2011).

According to the National Building Information Modeling Standard 2007, “A building information model is a digital representation of the physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward.” Architects, engineers, and constructors can use BIM for planning, designing, construction, and operation that will aid them to visualize the facility and identify any potential design, construction, or operational issues (Azhar 2011).

BIM implementation is advantageous during project planning (Ma, Shen, and Zhang 2005) and control phase (Feng, Chen, and Huang 2010). BIM implementation in the construction industry promises to enhance participant collaboration and communication through highly interoperable data (Hardin and McCool 2015) and its application to construction project management lowers the likelihood of delays and cost overruns (Tahir Muhammad et al. 2019). BIM creates information and processes essential for managing a facility throughout its lifecycle (Sher, Aranda-Mena, and Williams 2007). Literature suggests that practical application of BIM has positively impacted all the stages of a construction project.

BIM was implemented in the construction of Aquarium Hilton Garden Inn, Atlanta, Georgia with an objective to quantify its benefits. Over $200,000 were saved through clash detection and the schedule benefited by 1,143 hours (Azhar, Hein, and Sketo 2008). A thorough analysis of data from 32 large projects at Stanford University's Center for Integrated Facilities Engineering reveals that BIM can eliminate unbudgeted variations by up to 40%, cut the time it takes to prepare detailed cost estimates by about 80%, save the contract cost by up to 10% through clash detection, and shorten project duration by up to 7% (Gilligan and Kunz 2007).

2.4.1 BIM as a Tool for Risk Management

“A detailed BIM model is a risk mitigation tool” (Eastman et al., 2011). BIM views risk positively, and its modern tools present a range of opportunities that reduce design uncertainty and improve coordination among project stakeholders (Deutsch, 2011). An automated method for identifying safety-related risks and applying the corresponding mitigation techniques can be used by integrating BIM and safety (Zhang et al., 2013). Several BIM features can enhance visualization, lowering project participants' risk of incorrect design interpretation (Chantawit et al., 2005). However, there is limited published data on BIM and risk integration (Araszkiewicz, 2016; Zou et al., 2017).

A detailed study was conducted by (Ahmad et al., 2018) for identifying and quantifying the use of BIM in risk management to demonstrate whether the cost of its implementation can be balanced against the potential benefits of improved risk management. They concluded that the top risks were either eliminated or extensively addressed, which notably reduced their impact. Additionally, the value proposition of implementing BIM was higher due to its advantages, which supported investing in BIM. Another study by (Lu et al., 2014) used time-effort distribution curves for the evaluation of costs/benefits of BIM implementation in construction projects. The study concluded that while there is an increased effort at the design stage, it is beneficial to implement BIM.

As can be seen, nearly every study identifies BIM implementation and quantifies its effects on all project-related aspects or uses different techniques for quantification. However, there is no or significantly less information in the literature about the impact of BIM implementation on project cost overruns or the quantification of its advantages. It could be argued that BIM can lessen the impact of risks resulting in cost overruns, so it is essential to quantify the actual advantages of BIM on project cost performance.

2.5 List of Identified BIM Features

Through a thorough literature review, characteristics of BIM that have a positive impact on the project factors were identified for the current study. It is found that BIM features such as 3D visualization (Ghaffarianhoseini et al. 2017; Tulubas Gokuc and Arditi 2017), Collaboration and Communication or Sharing of information (Doumbouya, Gao, and Guan 2016; Eastman et al. 2011), Design Productivity and competitiveness (Chen, Agapiou, and Li 2020; Wong and Fan 2013), Object-oriented Parametric 3D Modeling (Doumbouya, Gao, and Guan 2016; Stanley and Thurnell 2014), Design Coordination (Clash Detection) (Azhar 2011; Chou and Chen 2017), Effective and Unambiguous Documentation including drawings (Bynum, Issa, and Olbina 2013; Jin et al. 2017), Planning and Scheduling (4D BIM) (Jin et al. 2017; Latiffi et al. 2013), Quantity Takeoff and Cost Estimation (Barlish and Sullivan 2012; Chou and Chen 2017) significantly influence the cost performance throughout project's lifecycle.

Extensive literature review was carried out to identify features of building information modelling (BIM). Table 2-2 contains the identified BIM features.

Table 2-2: List of BIM Features

Sr. #	**BIM Feature**	**Description**	**Source(s)**
	3D parametric modeling and visualization	BIM offers a virtual three-dimensional representation of the building, making it an excellent visualization tool. A better understanding of the potential final product can be gained through visualization.	(Azhar, 2011; Barlish & Sullivan, 2012; Cassino et al., 2010; Chiu & Lai, 2020; Chou & Chen, 2017; 2013; Cui & Tai, 2020; Doumbouya et al., 2016; Eastman et al., 2011; Franz & Messner, 2019; Ghaffarianhoseini et al., 2017; Hartmann et al., 2012; Hergunsel, 2011; Jin et al., 2017; khoshnava et al., 2012; Latiffi et al., 2013; Nisbet & Dinesen, 2010; Olanrewaju et al., 2021; Stanley & Thurnell, 2014; Tulubas Gokuc & Arditi, 2017; Vimonsatit & Foo, 2015; Wong & Fan, 2013)

Sr. #	**BIM Feature**	**Description**	**Source(s)**
2	Collaboration/Communication & sharing of information	BIM can be thought of as a digital process that incorporates every aspect, discipline, and system of a building (from design development to operation and maintenance), enhancing communication and teamwork among all project team members.	(Barlish & Sullivan, 2012; Bryde et al., 2013; Bynum et al., 2013; Cassino et al., 2010; Chen et al., 2020; Chiu & Lai, 2020; Chou & Chen, 2017; Doumbouya et al., 2016; Eastman et al., 2011; Ghaffarianhoseini et al., 2017; Hartmann et al., 2012; Jin et al., 2017; khoshnava et al., 2012; Latiffi et al., 2013; Nisbet & Dinesen, 2010; Olanrewaju et al., 2021; Stanley & Thurnell, 2014; Tulubas Gokuc & Arditi, 2017; Vimonsatit & Foo, 2015; Wong & Fan, 2013)
3	Design Productivity and competitiveness	By facilitating information sharing among the design team members, reducing change orders, reducing waste, and reducing redesign activities, BIM increases design productivity. According to the 2016 NBS survey, businesses using BIM have a clear competitive advantage.	(Cassino et al., 2010; Chen et al., 2020; Chiu & Lai, 2020; Computer Integrated Construction Research Program, 2013; Eastman et al., 2011; Ghaffarianhoseini et al., 2017; Latiffi et al., 2013; Nisbet & Dinesen, 2010; Tulubas Gokuc & Arditi, 2017; Wong & Fan, 2013)

Sr. #	BIM Feature	Description	Source(s)
4	Design Coordination (Clash Detection)	Clash detection is a very useful feature in BIM modeling tools. It finds clashes in the amalgam of structural, architectural and MEP Models. BIM saves 10% of contract value through clash detection.	(Azhar, 2011; Bryde et al., 2013; Chiu & Lai, 2020; Chou & Chen, 2017; Computer Integrated Construction Research Program, 2013; Eastman et al., 2011; Franz & Messner, 2019; Hergunsel, 2011; khoshnava et al., 2012; Latiffi et al., 2013; Nisbet & Dinesen, 2010; Olanrewaju et al., 2021; Stanley & Thurnell, 2014; Vimonsatit & Foo, 2015; Wong & Fan, 2013)
5	Effective and Unambiguous Documentation including drawings	For any particular group of objects or specific project view, drawings can be extracted. As a result, producing construction drawings for all design disciplines takes much less time and involves far fewer mistakes. Additionally, the accuracy and consistency of BIM data can lessen mistakes and omissions and rework, which can lower construction costs.	(Bynum et al., 2013; Cassino et al., 2010; Chen et al., 2020; Chiu & Lai, 2020; Doumbouya et al., 2016; Eastman et al., 2011; Jin et al., 2017; Latiffi et al., 2013; Nisbet & Dinesen, 2010)

Sr. #	**BIM Feature**	**Description**	**Source(s)**
6	Planning and Scheduling (4D BIM)	Integration of fourth dimension i.e. time, is known as 4D-BIM which allows you to discover and estimate a project's execution sequence, visualize construction processes through 4D simulation, identify clashes of any sort, manage an effective coordination between project participants throughout the design and construction process, and better predict, manage and communicate project outcomes.	(Azhar, 2011; Barlish & Sullivan, 2012; Bryde et al., 2013; Bynum et al., 2013; Cassino et al., 2010; Chen et al., 2020; Chou & Chen, 2017; Cui & Tai, 2020; Eastman et al., 2011; Franz & Messner, 2019; Ghaffarianhoseini et al., 2017; Hartmann et al., 2012; Hergunsel, 2011; khoshnava et al., 2012; Latiffi et al., 2013; Nisbet & Dinesen, 2010; Olanrewaju et al., 2021)
7	Safety Analysis	A useful technique for locating, assessing, and managing safety-related risks in the construction industry is safety analysis, also known as hazard analysis. BIM helps safety analysis by visualizing various site scenarios.	(Cassino et al., 2010; Chen et al., 2020; Computer Integrated Construction Research Program, 2013; Eastman et al., 2011; Jin et al., 2017; khoshnava et al., 2012; Latiffi et al., 2013; Zhang et al., 2013)
8	Prefabrication	Prefabrication will keep playing a crucial role in boosting efficiency and productivity throughout the construction process. Prefabrication using BIM will enhance quality and productivity, ultimately leading to a better project process.	(Cassino et al., 2010; Chou & Chen, 2017; Cui & Tai, 2020; Eastman et al., 2011; Hergunsel, 2011; Jin et al., 2017; Nisbet & Dinesen, 2010)

Sr. #	BIM Feature	Description	Source(s)
9	Quantity Takeoff and Cost Estimation	Quantity take-offs (QTO) are a comprehensive estimation of materials required to efficiently complete a construction project without much wastage. These estimated are prepared by an experienced estimator before start of construction phase.	(Barlish & Sullivan, 2012; Bynum et al., 2013; Cassino et al., 2010; Chou & Chen, 2017; Eastman et al., 2011; Hartmann et al., 2012; Hergunsel, 2011; Latiffi et al., 2013; Nisbet & Dinesen, 2010; Olanrewaju et al., 2021; Stanley & Thurnell, 2014)
10	Code Reviews	Designs are done by consulting various codes which includes structures, size, HVAC, type of construction, sustainability etc. BIM provides platform which checks building design against code requirements.	(Azhar, 2011; Jung & Joo, 2011; Kim & Teizer, 2014; Sami Ur Rehman et al., 2020b)
11	MEP systems	BIM software offers tool for designing, detailed estimating, fabrication and installation of MEP systems.	(Azhar, 2011; Bynum et al., 2013; Cassino et al., 2010; Sami Ur Rehman et al., 2020b)
12	Facility management	BIM is an information management tool which stores loads of data related to building while modeling. It creates many manuals which helps in maintaining and operating the facility during its lifecycle.	(Barlish & Sullivan, 2012; Computer Integrated Construction Research Program, 2013; Franz & Messner, 2019; Jin et al., 2017; Nisbet & Dinesen, 2010; Olanrewaju et al., 2021)

Sr. #	BIM Feature	Description	Source(s)
13	Risk Management	BIM helps in risk management by elimination of manual extraction of drawings, reducing the design deficiency and integrating design with construction.	(Bryde et al., 2013; Kim & Teizer, 2014; Sami Ur Rehman et al., 2020b; Stanley & Thurnell, 2014)
14	Energy Analysis	Energy analyses are usually known as Building Energy Modeling (BEM). BEM is an efficient tool to calculate energy consumptions for a facility for code reviews, retrofit designs, LEED certifications and planning and design of various systems.	(Azhar, 2011; Bynum et al., 2013; Cassino et al., 2010; Computer Integrated Construction Research Program, 2013; Eastman et al., 2011; Franz & Messner, 2019; Nisbet & Dinesen, 2010; Wong & Fan, 2013)
15	Interoperability	The capacity for information exchange between two or more systems is known as interoperability. It is one of the pillars of BIM because a BIM model's information needs to be exchanged in order to be useful.	(Bynum et al., 2013; Cassino et al., 2010; khoshnava et al., 2012; Nisbet & Dinesen, 2010)

2.6 Matrix between Key Risk Factors and Features of BIM

As discussed in the objectives of this research, our first course of action was to find key risk factors, which effects the project cost performance, through extensive literature review. Our second objective was to identify features of BIM which address the risks involved in construction projects. After achieving both these objectives, the next step in the research is to make a factor-feature matrix shown in table 2-3. The main purpose of factor-feature matrix is to identify key risk factors which can be resolved using adequate features of BIM. After listing down all key risk factors along Y-axis and features of BIM along X-axis, we would now be able to visualize that which feature of BIM affects which key risk factor. Moving forward, we are now ready to go ahead with the verification of this matrix through interviews or questionnaire from BIM experts and project managers, who are engaged in projects where BIM is already implemented.

Table 2.3: Feature-Factor Matrix

BIM Features / **Risk Factors**	3d parametric modeling and visualization	Collaboration, Coordination, Communication & Sharing of Information	Design Productivity and competitiveness	Design Coordination (Clash Detection)	Quantity Takeoff and Cost Estimation (5D BIM)	Planning and Scheduling (4D BIM)	Safety Analysis	Prefabrication	Effective/Unambiguous Documentation including drawings	Interoperability	Code Reviews	MEP systems	Risk Management	Energy Analysis	Facility management	Frequency
Poor and incomplete design	1	1	1	1	1						1					
Delays and changes in design	1	1	1	1	1						1					
Poor and Inaccurate cost estimation of the project	1	1			1											
Poor and Inaccurate time estimation of the project	1	1				1										
Delay in client's decision-making or issuing instructions	1	1	1	1	1	1					1		1			
Poor initial planning & scheduling	1	1				1										
Inaccurate quantity take-off	1			1	1											
Communication/Coordination problems between parties	1	1		1	1	1			1	1	1		1			
Drawing changes and errors	1	1		1					1							
Omissions and errors in BOQ	1	1			1				1							
Wastage on site								1								
Contractual Claims and Disputes	1															
Inadequate specifications and Information		1														
Mistakes and discrepancies in construction documentations		1							1							

BIM Features / Risk Factors	3d parametric modeling and visualization	Collaboration, Coordination, Communication & Sharing of Information	Design Productivity and competitiveness	Design Coordination (Clash Detection)	Quantity Takeoff and Cost Estimation (5D BIM)	Planning and Scheduling (4D BIM)	Safety Analysis	Prefabrication	Effective/Unambiguous Documentation including drawings	Interoperability	Code Reviews	MEP systems	Risk Management	Energy Analysis	Facility management	Frequency
Lack of risk management	1	1		1	1	1	1						1			
Inadequate safety measures	1	1				1	1			1			1			
Poor site management and supervision							1						1			
Client-initiated variations or change orders		1	1													
Unrealistic contract duration and requirements imposed						1										
Poor cost and financial control													1			
Poor Contract Administration																
Poor Project Management																
Poorly defined scope/Change in scope																
Size and complexity of the project																
Assigning contract to lowest																
Delay in procurement of materials and equipment																
Inappropriate procurement method																
Inflation and fluctuation of material and machine prices																
Unavailability of Labor (Skilled/Unskilled)																
Location of site or Poor access to site																
Unfavorable site and weather conditions																
Contractor's resource deficiency/ Financial problems																
Lack of client's experience																
Inefficient contractor performance and experience																
Financial constraints of client																
Poor labor productivity																

2.7 Risk Analysis Methods

Risk is that component of uncertainty, which can be quantified and the probability of occurrence and the severity of the harm can be estimated. Therefore, risk analysis is crucial for decision making and construction work coordination. Even during a construction project's planning and programming stages, the risk analysis is regarded as an analysis of unfavorable outcomes (Dziadosz & Rejment, 2015).

Risk can be analyzed using a variety of quantitative and qualitative techniques. Academics have used different strategies while dealing with uncertainty in construction projects, including decision tree analysis, probabilistic and impact assessment, statistical methods, Monte Carlo simulation, critical path method (CPM) and program evaluation and review technique (PERT) approaches, analytical hierarchical process, (SWOT) analysis, building information modeling (BIM), fuzzy set theory, and more. (Sadeh et al., 2021).

2.8 Fuzzy Logic Method

Lotfi Zadeh established the idea of Fuzzy set theory, in 1960. It is a mathematical approach to compute and model subjective human thought process i.e. it computes “degree of truth” rather than the usual “true” or “false” logic. (Bukh & Dickstein, n.d.) used fuzzy logic for the quantification of public risk perception towards the nuclear field. Similarly, (Pokoradi, 2022) used fuzzy logic for risk assessment. (Sadeh et al., 2021) developed a novel method that combined a Monte Carlo simulation with a fuzzy subjective system that was used objectively by establishing standards for experts. A methodology was reported by (Siddhappa K & Konnur, 2016) to resolve risk analysis issues pertaining to the construction sector with the goal of determining the appeal of the project using fuzzy logic.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the strategy that will be used to accomplish the research's goals, which were outlined in Chapter 1. Techniques like literature review, expert interviews, surveys and case study to be employed in this research.

3.2 Research Design

Research design is the integration of multiple techniques in a logical way to achieve predefined research objectives. The current study was conducted through four distinctive phases that include literature review, validation of factor-feature matrix, fuzzy logic model to assess pre-BIM risk level, BIM modeling and presentation, post-BIM risk level using fuzzy logic model, and results, analysis and discussions. The technique used in each phase is explained below. Figure 3.1 demonstrates a schematic representation of the research's working methodology.

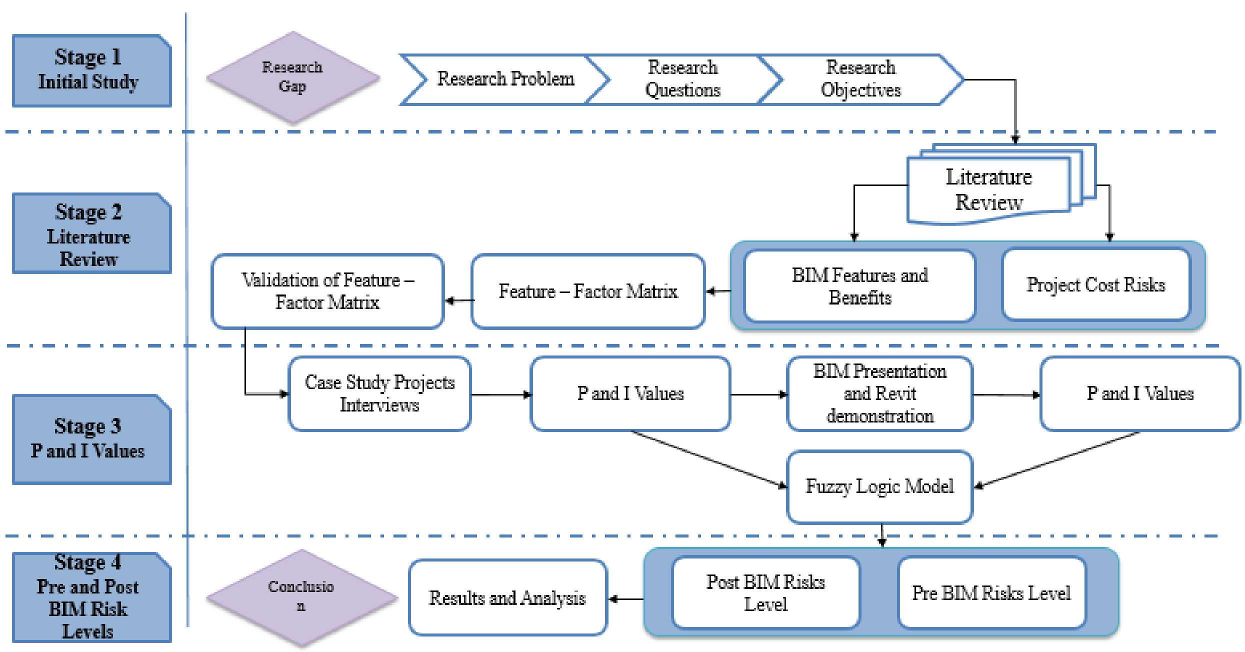

Figure 3.1: Research Framework

An extensive research methodology consisting of five distinct phases was used to successfully accomplish the study's goals and fill the identified research gap. Critical risk factors that lead to cost overruns and BIM features that positively impact different project phases were identified in the first phase. A thorough review of the literature was done for this purpose using the databases of the ASCE, Elsevier, Taylor & Francis, Emerald, Scopus, and Google Scholar. Further, to identify cost risk factors, keywords like "project cost overrun," "construction cost," and "construction cost risks" were used. Similar terms like "building information modeling," "features of BIM," and "tools of BIM" were also used to identify different BIM features. A total of 30 research papers were consulted to find the crucial risk factors that prevent the project from being completed successfully within budget, and 36 were found as a result. In order to find the features of BIM, 30 research papers were consulted, and 15 features were found. A factor-feature matrix was created after risk factors, and BIM features were identified, with the risk factors on the vertical axis and the BIM features on the horizontal axis. The matrix shows how a BIM feature affects a specific risk factor. The relationship between different risk factors and BIM features is defined in this matrix, which is crucial to this study because it serves as the foundation for all upcoming analyses, surveys, and case studies. It was created by consulting the BIM literature, which first identifies the feature and then explains its utility. The foundation of this study is this factor-feature matrix. For further studies, grouping was done for various identical risk factors. “*Design Problems*” contain “*poor and incomplete design*” and “*delays and changes in design*”. Similarly, “*Inaccurate Quantity Takeoff and Cost Estimation*” contain “*poor and inaccurate cost estimation of the project”* and “*inaccurate quantity take-off*”, “*Inaccurate Time Estimation”* includes “*poor and inaccurate time estimation of the project* “and “*unrealistic contract duration and requirements imposed*”, *“Poor Communication and Coordination”* contains *“communication/coordination problems between parties”* and *“contractual claims and disputes”*, *“Poor Site Management and Supervision”* also contain *“poor cost and financial control on site”, “wastage on site”* and *“inadequate safety measures”,* and “*Faulty Construction Documentation*” includes “*mistakes and discrepancies in construction documentations*”, “*omissions and errors in boq”, “drawing changes and errors”* and *"inadequate specifications and information".* The risk factors were grouped based on their shared characteristics and how they affect different risk factors.

A web-based international survey was carried out in the second phase for the validation of the factor-feature matrix. BIM experts and practitioners with practical knowledge made up the respondents. Through LinkedIn®, an online professional platform, a careful analysis of potential respondents' profiles was done to obtain accurate and logical data. In this regard, an analysis of the respondents' work history, current position, and previous jobs were conducted. As a result, the survey included more than 300 BIM professionals from around the globe. A formal request was made, and after receiving a favorable response, a link to a web-based survey created in Google Docs® was sent. There were 60 responses to this survey, conducted between March and August of 2021, for a response rate of 19.75 percent. The survey questionnaire was divided into two sections; section one covered the respondents' demographics. On a 5-point Likert scale, 1 represents "strongly disagree," 2 represents "disagree," 3 represents "neutral," 4 represents "agree," and 5 represents "strongly agree," the questions in Part 2 asked about specific BIM features that affect specific risk factors. For data reliability, statistical tests like Cronbach's alpha were run.

After evaluating cost risks and BIM features, it was necessary to involve the three main stakeholders (contractor, client, and consultant) in five ongoing projects to investigate and quantify the impact of BIM on cost performance. Pre-BIM risk levels and post-BIM risk levels were necessary for this. Since no project in Pakistan has contractually adopted BIM, five such projects were selected which were either in its construction or completion phase and for which all the documentation and information could be made available. All the projects' initial cost was over 1000 Million Pakistani rupees. The projects included both development and building projects with all the projects already overrun their original cost.

In the third phase, 15 experts (3 from every project: 1 participant each from client, consultant and contractor) were engaged to collect information on Probability and Impact of the identified risk factors that affect project cost. After collection of the data, a fuzzy logic model was created in MATLAB to assess the data and a risk level was obtained.

In the fourth phase, a detailed BIM presentation was given to all the participants explaining its features, benefits, and how it can mitigate or address the grouped risks. A 3-d architectural model of a residential building, developed using Revit, was explained to the experts on how it is beneficial for their projects in mitigating the identified risks. The same respondents were given access to numerous walkthroughs, screenshots, and reports. Following their detailed responses, participants were again asked to provide probability (P) and impact (I) values for each cost risk affecting project activities. In light of the data produced by the BIM, the respondents could inquire about and request clarifications. After collecting the data, the same was analyzed using the fuzzy logic model a post-BIM risk level was obtained. The analysis was completed following the fifth phase's comprehensive data collection and preparation. Based on this, results and analysis are presented, a discussion is made, and a conclusion and recommendations are drawn.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter covers the analysis carried out on the collected data. Results are drawn and detailed discussion is done over various findings in subsequent sections.

4.2 Identification of Risk Factors and BIM Features

From 30 research papers found 38 cost risk factors in the first phase. Risk analysis is therefore essential for project selection and coordination of construction work. Below some of the significant risks are discussed.

The top risk, reported in 26 papers, is “Inflation and fluctuation of material and machine prices”. Inflation is the rate of increase in general price level in an economy. Inflation, resulting in an increase of material and machine prices, affect the cost of construction resulting in project cost overrun (Abbas & Painting, 2017; Durdyev et al., 2017; Shiferaw Belachew et al., 2017). The second most frequent factor, reported in 23 papers, is “Communication and Coordination problems between parties”. Frequent co-ordination among all parties throughout the project life is necessary. Poor communication and coordination on a project during all stages leads to delay and cost overrun (Durdyev et al., 2010; Famiyeh et al., 2017; Memon et al., 2010). With 22 mentions, “Design Changes and Poor design” is third on the list of factors contributing to the project cost overrun. Frequent changes and delays in design could happen for various reasons and interrupt the planned schedule, especially if the changes lead to additional work or rework. Consequently, the project cost will increase (Bekr, 2015; Polat et al., 2014; Ramabodu & Verster, 2013). Other important factors include inaccurate cost and time estimation (Ramabodu & Verster, 2013), Delay in client’s decision-making process/ issuing instructions to contractor (Naveenkumar & Prabhu, 2016) and poor planning and scheduling (Ameh et al., 2010).

After the identification of risk factors, BIM features were gathered. In doing so, 15 BIM features were gathered from 30 research papers. "Collaboration, Coordination, Communication & Sharing of Information" topped the list with 21 mentions. BIM technology enables project participants' collaboration and multidisciplinary team integration, allowing for the identification and resolution of issues prior to construction (Doumbouya et al., 2016; Ghaffarianhoseini et al., 2017; Tulubas Gokuc & Arditi, 2017). With 19 mentions, "3D Parametric modeling & Visualization" is ranked second. Benefits of What You See Is What You Get (WYSIWYG) are provided by visualization through 3D models. It relieves us from creating a mental model while examining a 2D plan, which is a laborious and error-prone task. Better understanding of the potential final product is achieved through visualization (Eastman et al., 2011; Jin et al., 2017). Third in the list is "Planning and Scheduling (4-d BIM) with 18 mentions. The idea of integrating 3D modeling and time was first suggested by (Koo & Fischer, 2000) and it was named as Four-Dimensional Computer-Aided Design (4D-CAD). It allows us to discover and estimate a project's execution sequence, visualize construction processes through 4D simulation, identify clashes of any sort, manage an effective coordination between project participants better anticipate, manage, and communicate project outcomes throughout the design and construction process (Sami Ur Rehman et al., 2020a). Similar to this, other features significantly influencing various project-related aspects were also found. The fourth-placed feature, "Design Coordination (Clash detection)," also affects design, estimation, planning, and decision-making at different project stages. "Quantity Takeoff and Cost Estimation (5-d BIM)" adds cost estimating information to a BIM model. With a 3 percent error threshold and up to an 80 percent shortened generation time, BIM offers cost estimation. (Chien et al., 2014). All these factors affect various phases of project and their proper redress can ensure successful execution of the project.

4.3 Risk – factor and BIM – Feature Matrix

4.3.1 Formation of feature - factor matrix

A feature-factor matrix was created after the risks and BIM features were identified, as shown in Table 3.1. The BIM feature "Communication, Coordination, Collaboration and

Sharing of Information" impacts 14 risk factors when viewed horizontally downward from the top of the matrix. BIM makes it possible for all engineering stakeholders to work together on a single, shared model to accomplish the project's objectives. BIM's data sharing capabilities among team members enable ongoing evaluation and information control (Qian, 2012).

Similarly, “3-d parametric modeling and visualization” affects 13 risk factors and is second on the list. This feature affects the risk factor "delays and changes in design," as 3D design proposals can be rigorously analyzed, and various simulations can be quickly performed, enabling better and quicker designs (Azhar, 2011). Further, the factors include "inadequate safety measures"; this feature displays the 3-d object representing a project's physical condition, giving safety engineers information for analyzing and utilizing what safety measures are needed? When should the necessary actions be carried out? Where is it essential to adhere to safety rules? Why are particular safety precautions and measures needed in a given area? (Chantawit et al., 2005). Additionally, "communication and coordination issues among parties" is impacted because 3-D models and illustrations enable project managers and Jobsite engineers to learn more about the project and share their experience and knowledge of potential issues and solutions (Jan et al., 2013).

Further, “quantity take off/cost estimation,” ranked at number three, impact eight risks. Similarly, the BIM features “Design Coordination (clash detection)” and “Planning and Scheduling (4D BIM)” both ranked at number four, as they address seven risk factors each. Finally, “Risk Management” affects six risks and is at number five.

Looking at this matrix from horizontally rightward, risk factors “Communication/Coordination problems between parties” is affected by nine BIM features and “Delay in client’s decision making or issuing instructions” is affected by eight BIM features. Seven features affect “Lack of Risk Management” and the “Design Problems” are affected by Six BIM features. Some risks like "Inflation and fluctuation of material and machine prices" are not impacted by any of the identified BIM features, “Financial Constraints of Client”, “Inappropriate procurement methods”, unavailability of labors”, “unfavorable weather and site conditions” and “Assigning contract to the Lowest

Bidder". BIM adoption will not have any impact on these risks. Similar to this, some BIM features, such as "facility management and Energy Analysis," have no direct impact on any identified risk factors. These features have their value addition but in case of project cost management, their role is negligible.

4.3.2 Endorsement of Feature – Factor Matrix

Even though the feature – factor matrix summarizes and represents the current state of the literature, to address project cost issues, it was still required to get a professional opinion on how BIM features would affect the identified risk factors. In this regard, an international survey was conducted to verify the feature-factor matrix's efficacy and the literature review results, with data collected from 60 respondents. The reliability of results demands an adequate knowledge of BIM, level of understanding of BIM was asked from the respondents and the results are shown in Figure 2. These responses are highly appropriate for this study because it is clear that 60% of respondents were either experts or proficient in BIM, and only 13% of respondents were beginners.

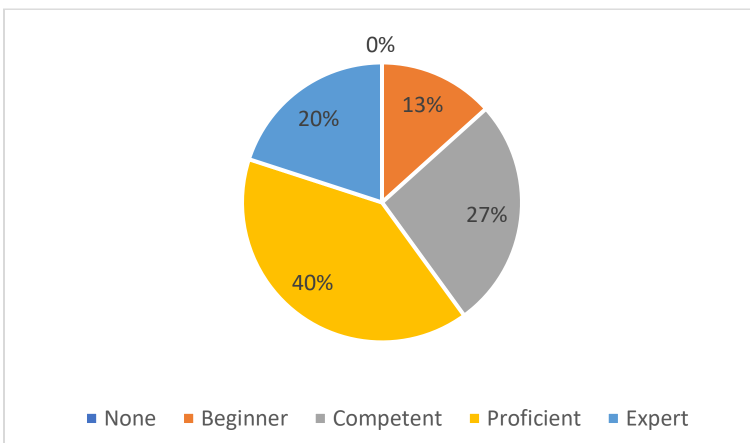

Figure 4.1: Respondents Level of Understanding of BIM

However, Cronbach's alpha test was conducted to ensure the reliability of the data for further analysis, and the results showed that the data was highly reliable, with an alpha (α) as shown in figure 3.

Case Processing Summary

		N	%
Cases	Valid	60	100.0
	Excluded[a]	0	.0
	Total	60	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.964	68

Figure 4.2: Cronbach's Alpha Value

Furthermore, the respondents belonged to different stakeholder organizations involved in the construction industry. The details in figure 4 show 33 % participation of consultants, 17 % architects and 25% of contractors. This increases the credibility of the findings because consulting firms with expertise in architecture and design are the most frequent BIM users.

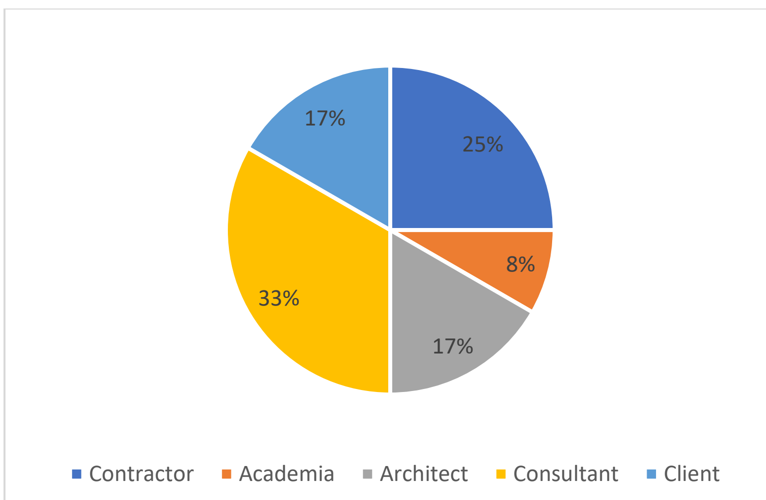

Figure 4.3: Respondents Organization

Per the analysis, most respondents strongly agreed with the effectiveness of some BIM features in addressing different risk factors. In total, 50% of respondents strongly agreed and 50% respondents agreed that "poor and incomplete design" can be affected by BIM feature “3-d Parametric modeling and Visualization”. Also, 58% respondents strongly agreed that this feature also mitigates the risk of “Delay and Changes in Design”. Going on, 75% respondents strongly agreed that “Quantity take off and Cost estimation (5d)” can positively address “Inaccurate Cost Estimation”. Similarly, “3-d Parametric modeling & Visualization” and “Collaboration, Coordination, Communication & Sharing of Information” gets 60 % strong agreement for affecting “Communication and Coordination problems among parties”. To mitigate “Poor Planning and Scheduling” risk, 92 % respondents either agreed or strongly agreed that it can be done by the BIM feature “Planning and Scheduling (4d)”. More than 80% respondents either agreed or strongly agreed with all the questions listed in the questionnaire. As a result, the literature review is verified, and the factor-feature matrix is now a valid tool for mapping the advantages of BIM. Additionally, it offers a valuable collection of methods for minimizing various cost-related risks by utilizing various BIM features. Hence, this matrix is suitable for additional research and analysis.

4.4 Fuzzy Logic Model

Lotfi A. Zadeh in 1965 established a mathematical approach, Fuzzy set theory, to simulate the subjective and intellectual thought process of humans. Membership functions and a set of rules convert linguistic terms to numerical values into enable the use of probability-based decision-making. A group of membership functions with values between 0 and 1 define it (Zadeh, 1965). Zero indicates an event that has no chance of happening, 0.5 represents an event that has a 50% chance of happening, and 1 denotes an event that will definitely happen. (Nieto-Morote & Ruz-Vila, 2011) cite their review to assert that fuzzy risk evaluation systems adhere to the following rules: (i) defining the parameters, (ii) establishing the fuzzy inference, and (iii) defuzzification. Steps to model a fuzzy inference system are defined by Sharma and Goyal (2015) and are given below:

1. The primary determinants or indicators of the dependent variable are independent variables.
2. Fuzzy sets are created for independent and dependent variables. These define a variable in spoken language instead of numerical values. The

membership function describes how realistically each variable is a member of a fixed fuzzy set.

3. The fuzzy inference model incorporates built rules.
4. Independent variables and inference rules are used to create the fuzzy output set for the dependent variable. A number then represents the fuzzy output set after deffuzzification.

Fuzzy logic can model complex nonlinear functions, is adoptable and tolerant to imprecise data, is based on natural language, can be built using conventional control techniques, is based on natural language, and can be built on top of the experiences of experts. Fuzzy logic is designed to make it easy to understand. It can also be made to correspond to any set of input-output data. Fuzzy Logic Toolbox software includes adaptive methods like Adaptive Neuro-Fuzzy Inference Systems (ANFIS), which make this process notably simple (Sadeh et al., 2021). A simple Fuzzy Logic architecture can be seen in figure 4.

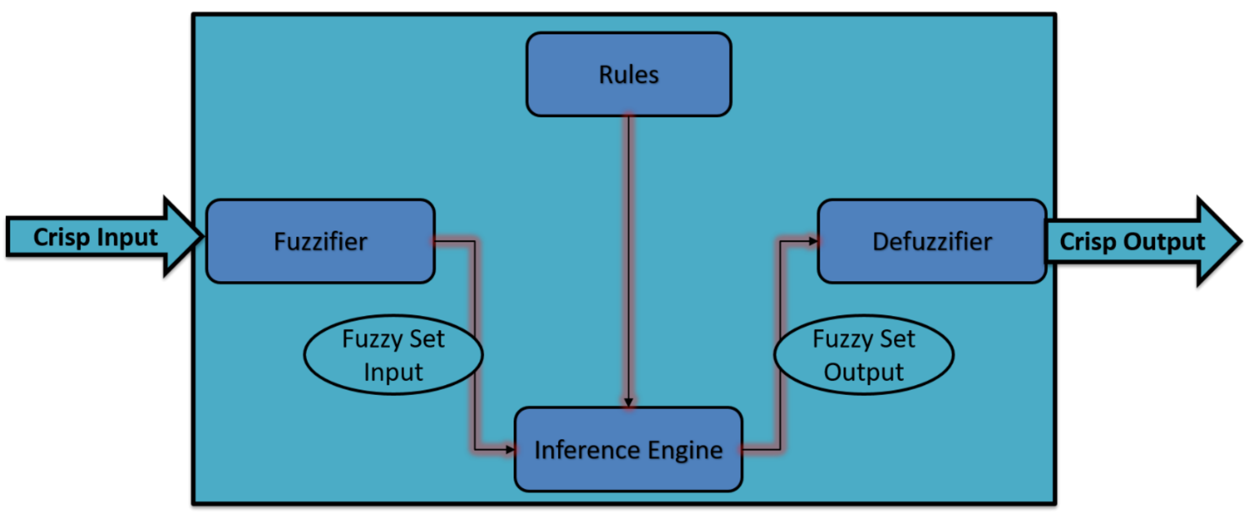

Figure 4.4: Fuzzy Logic Architecture

The fuzzy logic toolbox in MATLAB is used to develop the model in the following steps, which are based on the fuzzy logic method literature and MathWorks guidelines:

1. Create and specify variables for input and output. Figure 5 illustrates the relationship between the inputs, impact and probability, and the output risk level. The experts ranked the severity of each risk using the inputs as criteria.

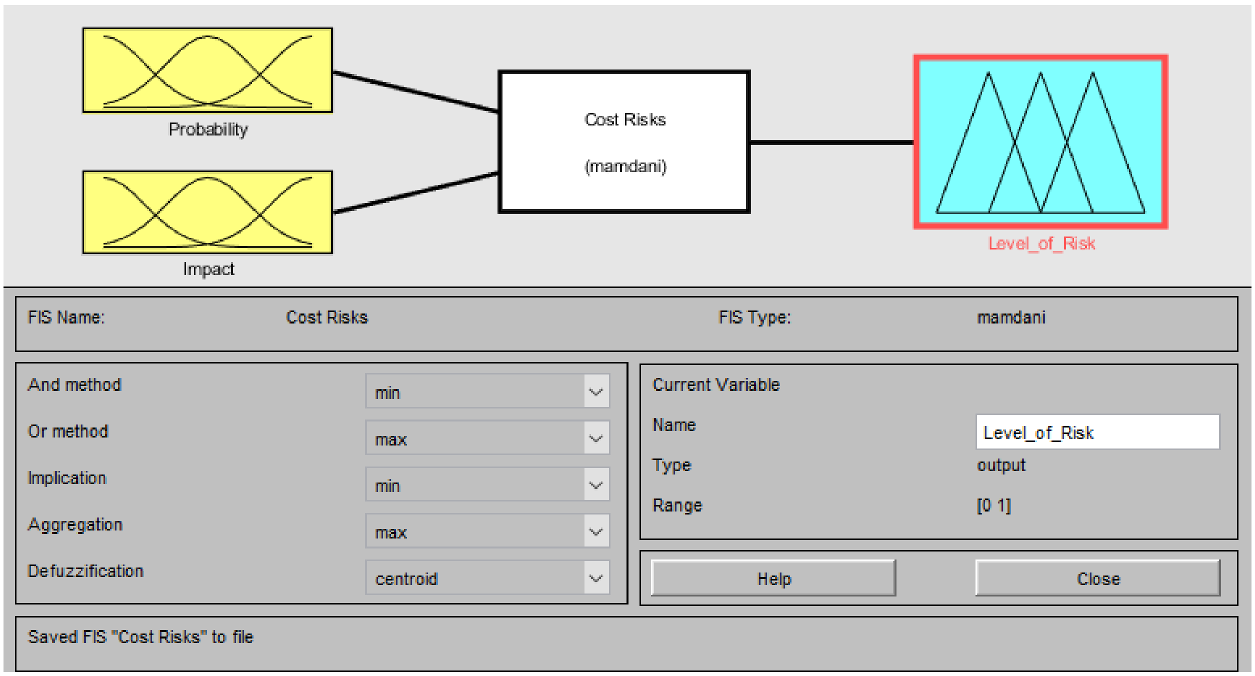

Figure 4.5: Input and Output Variables

2. A curve known as the membership function (MF) explains how each input point is connected to a membership value between [0] and [1]. As shown in Fig. 6, *outputs* are defined as a low, medium, high, and very high for inputs and low, medium, high, and very high for outputs.

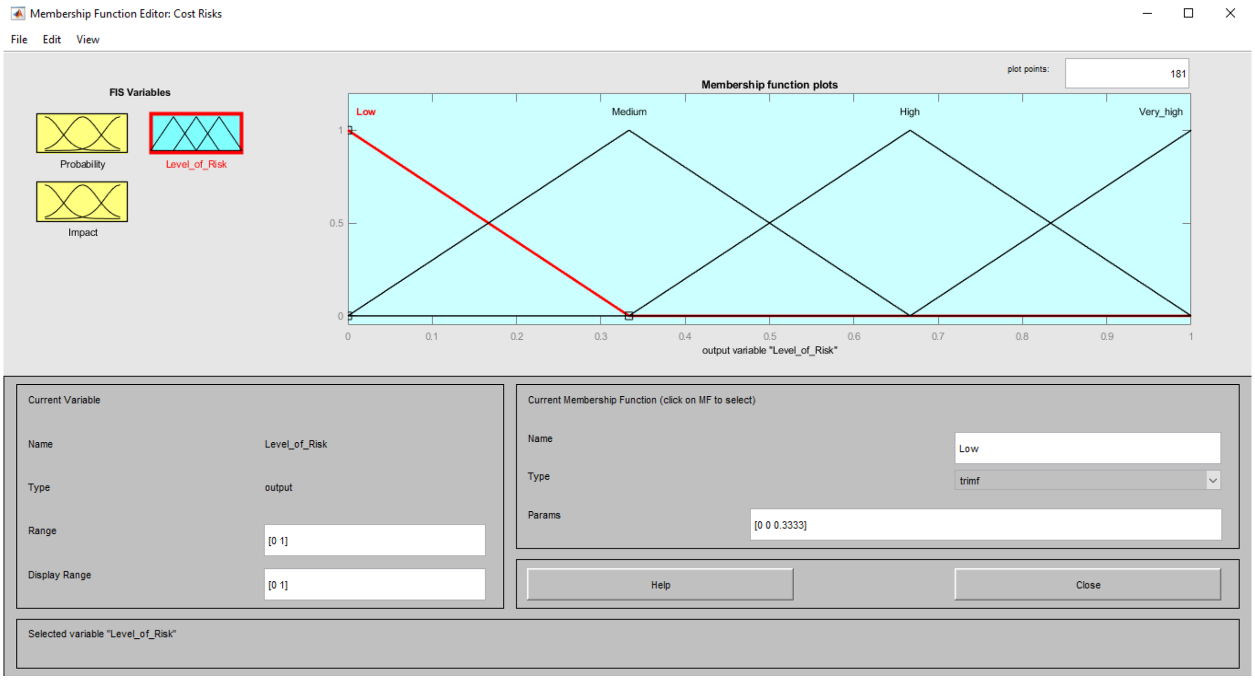

Figure 4.6: Membership Functions Defined

3. Rules are established to connect input and output variables. There are 25 rules for this model that are defined as if-then statements based on the input and output variables, as shown in Table 4.1.

Table 4.1: Rules for Input and Output Variables

	Probability	*Impact*	*Level of Risk*
1	**If** *Probability* is Very Low	**And** *Impact* is Very Low	**Then** *Level of Risk* is Low
2	**If** *Probability* is Very Low	**And** *Impact* is Low	**Then** *Level of Risk* is Low
3	**If** *Probability* is Very Low	**And** *Impact* is Medium	**Then** *Level of Risk* is Low
4	**If** *Probability* is Very Low	**And** *Impact* is High	**Then** *Level of Risk* is Medium
5	**If** *Probability* is Very Low	**And** *Impact* is Very High	**Then** *Level of Risk* is High
6	**If** *Probability* is Low	**And** *Impact* is Very Low	**Then** *Level of Risk* is Low
7	**If** *Probability* is Low	**And** *Impact* is Low	**Then** *Level of Risk* is Low
8	**If** *Probability* is Low	**And** *Impact* is Medium	**Then** *Level of Risk* is Medium
9	**If** *Probability* is Low	**And** *Impact* is High	**Then** *Level of Risk* is High
10	**If** *Probability* is Low	**And** *Impact* is Very High	**Then** *Level of Risk* is High
11	**If** *Probability* is Medium	**And** *Impact* is **Very Low**	**Then** *Level of Risk* is Medium
12	**If** *Probability* is Medium	**And** *Impact* is Low	**Then** *Level of Risk* is Medium
13	**If** *Probability* is Medium	**And** *Impact* is Medium	**Then** *Level of Risk* is High
14	**If** *Probability* is Medium	**And** *Impact* is High	**Then** *Level of Risk* is High
15	**If** *Probability* is Medium	**And** *Impact* is Very High	**Then** *Level of Risk* is Very High
16	**If** *Probability* is High	**And** *Impact* is Very Low	**Then** *Level of Risk* is High
17	**If** *Probability* is High	**And** *Impact* is Low	**Then** *Level of Risk* is High

18	**If** *Probability* is High	**And** *Impact* is Medium	**Then** *Level of Risk* is Very High
19	**If** *Probability* is High	**And** *Impact* is High	**Then** *Level of Risk* is Very High
20	**If** *Probability* is High	**And** *Impact* is Very High	**Then** *Level of Risk* is Very High
21	**If** *Probability* is Very High	**And** *Impact* is Very Low	**Then** *Level of Risk* is High
22	**If** *Probability* is Very High	**And** *Impact* is Low	**Then** *Level of Risk* is Very High
23	**If** *Probability* is Very High	**And** *Impact* is Medium	**Then** *Level of Risk* is Very High
24	**If** *Probability* is Very High	**And** *Impact* is High	**Then** *Level of Risk* is Very High
25	**If** *Probability* is Very High	**And** *Impact* is Very High	**Then** *Level of Risk* is Very High

4. The process of converting linguistic terms to fuzzy sets is called defuzzification. After the model has completed the defuzzification process to turn the values into crisp values, the risk level is calculated based on probability and cost impact for each factor.

4.4.1 Risk Level Using Fuzzy Logic

The triangular average formula (Bojadziev and Bojadziev 2007), was used to determine the level of grouped risks based on the opinions of experts. A1 and An are fuzzy numbers, and a_1, a_m, and a_2 correspond to triangular fuzzy numbers for linguistic variables.

$$A_{avg} = \frac{A1 + \cdots An}{n}$$

The following equation was used in order to determine best nonfuzzy performance (BNP) values

$$BNP = \frac{((a2 - a1) + (am - a1))}{3} + a_1$$

As, the crisp values of inputs were changed into Fuzzy values and their BNP values are shown in the following Table 4.2.

Table 4.2: Fuzzy and BNP Values for Crisp Inputs

Inputs	Crisp Value	Fuzzy Value	BNP Value
Probability / Impact	5	[0.75 1 1]	0.916
	4	[0.5 0.75 1]	0.750
	3	[0.25 0.50 0.75]	0.500
	2	[0 0.25 0.5]	0.250
	1	[0 0 0.25]	0.083

4.5 Pre – BIM Risk Level

In the third phase of this study, pre-BIM risk levels were calculated. For this purpose, 15 experts from five different construction projects were asked to provide probability (P) and impact (I) of the grouped risks influencing project activities. The participants were interviewed separately and were allowed to ask questions and clarifications regarding the risks. It was interesting to observe that all the projects had faced cost overrun already and one of the projects was at halt due to cost issues.

It was intriguing to note during the interviews how different stakeholders view the consequences of risk factors differently. The client and contractor rated the risk factors higher that come into the account of consultant or designer like "*Design Problems*". Similarly, contractors rated "*Delay in client decision making*" risk highly. This contrast is primarily based on the project participants' abilities, professional backgrounds, and contractual commitments (Ahmad et al., 2018).

It was observed that all the experts rated the "Poor Communication and Coordination" equally high. However, as rightly observed by (Sami Ur Rehman et al., 2020b) clients seemed unhappy that the contractor mostly conceals information whether to exploit the circumstance and subsequently seek financial gain. On the other hand, the contractors blamed the client and consultant for providing delayed, incomplete and inaccurate data/information, which hinders the progress on the contractors' part. All the stakeholders agreed that many managerial, technical, and administrative issues could be resolved early in the project with no time and cost losses if all parties made sure there was proper coordination.

After getting the "P" and "I" values from all the experts, these were run in the fuzzy logic model to get the averaged level of risk for all the risks. Table 4-3 shows the same.

It can be observed from the table that *"Poor Communication and Coordination"* has the highest risk level of 0.842 while "*Poor Site Management and Supervision*" has the lowest risk level of 0.718. With this data, it can be guessed that the projects need to be risk proof since the beginning. This also suggests that BIM should be applied throughout the process starting from the design while involving all the stakeholders.

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Design Problems	E_1	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_2	3	[0.25 0.50 0.75]	0.50	5	[0.75 1 1]	0.916	0.667
	E_3	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_4	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_5	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_6	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_7	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_8	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_9	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_{10}	5	[0.75 1 1]	0.916	3	[0.25 0.50 0.75]	0.50	0.892
	E_{11}	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_{12}	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_{13}	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_{14}	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_{15}	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
Risk Level								**0.825**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Inaccurate Quantity Takeoff and Cost Estimation	E_1	3	[0.25 0.50 0.75]	0.50	5	[0.75 1 1]	0.916	0.667
	E_2	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_3	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_4	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_5	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_6	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_7	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_8	3	[0.25 0.50 0.75]	0.50	5	[0.75 1 1]	0.916	0.743
	E_9	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{10}	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_{11}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{12}	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{13}	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_{14}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{15}	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	Risk Level							**0.792**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Inaccurate Time Estimation	E_1	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_2	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_3	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_4	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_5	3	[0.25 0.50 0.75]	0.50	5	[0.75 1 1]	0.916	0.743
	E_6	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_7	5	[0.75 1 1]	0.916	3	[0.25 0.50 0.75]	0.50	0.892
	E_8	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_9	2	[0 0.25 0.5]	0.25	5	[0.75 1 1]	0.916	0.667
	E_{10}	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{11}	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{12}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{13}	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_{14}	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_{15}	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	Risk Level							**0.792**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Delay in Client Decision Making	E_1	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_2	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_3	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_4	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_5	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_6	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_7	5	[0.75 1 1]	0.916	3	[0.25 0.50 0.75]	0.50	0.892
	E_8	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_9	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_{10}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{11}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_{12}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_{13}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{14}	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_{15}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	Risk Level							**0.727**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Poor Communication and Coordination	E_1	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_2	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_3	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_4	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_5	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_6	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_7	5	[0.75 1 1]	0.916	3	[0.25 0.50 0.75]	0.50	0.892
	E_8	4	[0.5 0.75 1	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_9	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_{10}	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_{11}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_{12}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{13}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_{14}	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_{15}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	Risk Level							**0.847**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Poor Planning and Scheduling	E_1	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_2	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_3	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_4	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_5	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_6	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_7	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_8	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_9	2	[0 0.25 0.5]	0.25	4	[0.5 0.75 1]	0.75	0.667
	E_{10}	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{11}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_{12}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{13}	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_{14}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_{15}	3	[0.25 0.50 0.75]	0.50	5	[0.75 1 1]	0.916	0.743
	Risk Level							**0.822**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Poor Site Management & Supervision	E_1	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_2	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_3	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_4	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_5	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_6	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_7	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_8	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_9	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_{10}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{11}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{12}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{13}	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_{14}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{15}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	Risk Level							**0.720**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Faulty Construction Documents	E_1	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_2	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_3	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_4	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_5	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_6	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_7	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_8	3	[0.25 0.50 0.75]	0.50	5	[0.75 1 1]	0.916	0.743
	E_9	2	[0 0.25 0.5]	0.25	5	[0.75 1 1]	0.916	0.667
	E_{10}	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_{11}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{12}	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{13}	2	[0 0.25 0.5]	0.25	4	[0.5 0.75 1]	0.75	0.667
	E_{14}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{15}	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	Risk Level							**0.725**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level (Fuzzy Value)
Lack of Risk Management	E_1	5	[0.75 1 1]	0.916	3	[0.25 0.50 0.75]	0.50	0.892
	E_2	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_3	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_4	3	[0.25 0.50 0.75]	0.50	4	[0.5 0.75 1]	0.75	0.667
	E_5	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_6	3	[0.25 0.50 0.75]	0.50	5	[0.75 1 1]	0.916	0.743
	E_7	5	[0.75 1 1]	0.916	4	[0.5 0.75 1]	0.75	0.892
	E_8	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_9	4	[0.5 0.75 1]	0.75	3	[0.25 0.50 0.75]	0.50	0.892
	E_{10}	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{11}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	E_{12}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{13}	4	[0.5 0.75 1]	0.75	4	[0.5 0.75 1]	0.75	0.892
	E_{14}	4	[0.5 0.75 1]	0.75	5	[0.75 1 1]	0.916	0.892
	E_{15}	5	[0.75 1 1]	0.916	5	[0.75 1 1]	0.916	0.892
	Risk Level							**0.822**

Table 4.3: Pre-BIM Risk Level

4.6 Post – BIM Risk Level

In the fourth phase of this study, the post-BIM risk level was calculated. However, since BIM was not implemented in these projects initially, a BIM model was developed for the case studies, as shown in Figures a and b. In addition, a detailed presentation was given to all the stakeholders, elaborating on BIM benefits and how BIM mitigates the identified risks. The stakeholders in the project were given information about BIM, its implementation, and its advantages using the model and presentation. These presentations were essential in educating all the stakeholders about the advantages of BIM concerning the identified risks. To fully comprehend the state of project risk following the implementation of BIM, the participants had the opportunity to ask questions and request clarifications. At the end of each presentation, each risk's probability (P) and impact (I) on the project were gathered and organized to get the post-BIM risk level as shown in table 4-4.

All respondents were convinced that effective BIM implementation not only reduces risks but also opens up several opportunities. In calculating the post BIM risk levels, it was observed that as a result of proactive risk management through BIM, the risk levels of all the identified risks reduced drastically. BIM not only reduces the probability of these risks but also the impacts.

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Design Problems	E_1	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_2	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_3	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_4	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_5	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_6	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_7	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_8	1	[0 0 0.25]	0.083	4	[0.5 0.75 1]	0.75	0.454
	E_9	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_{10}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{11}	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_{12}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{13}	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_{14}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{15}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	Risk Level							**0.254**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Inaccurate Quantity Takeoff and Cost Estimation	E_1	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_2	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_3	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_4	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_5	1	[0 0 0.25]	0.083	1	[0 0 0.25]	0.083	0.118
	E_6	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_7	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_8	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_9	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_{10}	3	[0.25 0.50 0.75]	0.5	2	[0 0.25 0.5]	0.25	0.333
	E_{11}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{12}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{13}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{14}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{15}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	Risk Level							**0.169**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Inaccurate Time Estimation	E_1	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_2	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_3	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_4	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_5	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_6	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_7	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_8	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_9	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{10}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{11}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{12}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{13}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{14}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{15}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	Risk Level							**0.190**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Delay in Client Decision Making	E_1	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_2	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_3	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_4	1	[0 0 0.25]	0.083	1	[0 0 0.25]	0.083	0.118
	E_5	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_6	1	[0 0 0.25]	0.083	1	[0 0 0.25]	0.083	0.118
	E_7	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_8	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_9	1	[0 0 0.25]	0.083	1	[0 0 0.25]	0.083	0.118
	E_{10}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{11}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{12}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{13}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{14}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_{15}	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	Risk Level							**0.279**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Poor Communication and Coordination	E_1	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_2	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_3	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_4	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_5	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_6	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_7	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_8	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_9	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{10}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{11}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{12}	1	[0 0 0.25]	0.083	1	[0 0 0.25]	0.083	0.118
	E_{13}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{14}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{15}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	Risk Level							**0.212**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Poor Planning and Scheduling	E_1	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_2	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_3	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_4	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_5	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_6	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_7	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_8	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_9	1	[0 0 0.25]	0.083	1	[0 0 0.25]	0.083	0.118
	E_{10}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{11}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{12}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{13}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{14}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{15}	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	Risk Level							**0.208**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Poor Site Management & Supervision	E_1	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_2	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_3	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_4	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_5	3	[0.25 0.50 0.75]	0.50	3	[0.25 0.50 0.75]	0.50	0.667
	E_6	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_7	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_8	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_9	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{10}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{11}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{12}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{13}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_{14}	1	[0 0 0.25]	0.083	1	[0 0 0.25]	0.083	0.118
	E_{15}	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	Risk Level							**0.207**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Faulty Construction Documents	E_1	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_2	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_3	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_4	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_5	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.083	0.118
	E_6	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_7	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_8	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_9	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{10}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{11}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{12}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{13}	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_{14}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{15}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	Risk Level							**0.160**

Risks	Experts	Probability	Fuzzy Value	BNP Value	Impact	Fuzzy Value	BNP Value	Risk Level
Lack of Risk Management	E_1	3	[0.25 0.50 0.75]	0.50	1	[0 0 0.25]	0.083	0.333
	E_2	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	E_3	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_4	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_5	3	[0.25 0.50 0.75]	0.50	2	[0 0.25 0.5]	0.25	0.333
	E_6	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_7	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_8	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_9	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{10}	1	[0 0 0.25]	0.083	2	[0 0.25 0.5]	0.25	0.118
	E_{11}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{12}	2	[0 0.25 0.5]	0.25	1	[0 0 0.25]	0.08	0.118
	E_{13}	2	[0 0.25 0.5]	0.25	2	[0 0.25 0.5]	0.25	0.118
	E_{14}	1	[0 0 0.25]	0.083	3	[0.25 0.50 0.75]	0.50	0.256
	E_{15}	2	[0 0.25 0.5]	0.25	3	[0.25 0.50 0.75]	0.50	0.333
	Risk Level							**0.185**

Table 4.4: Post-BIM Risk Level

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter concludes the research by stating and summarizing the inferences, findings and recommendations for future research. The insight will help the reader to understand the crux of the study and parting ways for future endeavors related to this area of research.

5.2 Conclusion

Although significant research has focused on identifying, classifying, and mitigating risk factors that lead to cost overruns, construction projects still experience overruns, ultimately leading to project failure. Modern ICT tools have been used in numerous attempts to control the causes of cost overruns; most recently, BIM has wholly changed how ICT tools impact different aspects of construction projects. The published research established that BIM significantly affects the resolution of cost-related challenges, but research has not yet quantified its advantages. This served as the foundation for the current study, which sought to identify risk factors, BIM features, and their relationships. Pre-BIM and post-BIM risk levels, computed using the Fuzzy Logic Model, were used to calculate the impact of BIM on risk factors to assess BIM's effectiveness in cost risk management. Multiple cost risk factors are seen to be directly addressed by BIM features. It is observed that many of the cost risk factors are directly mitigated by BIM features (decreases the risk level) i.e. BIM protects stakeholders from rework by detecting clashes in the design at an early stage. Similarly 3D BIM helps stakeholders to make informed decisions and 5D BIM helps in mitigating the risk of inaccurate quantity and cost estimates. After involving project stakeholders and performing risk management, it has been found that BIM not only reduces the overrun prompted by risks but also can bring opportunities for the project..

5.3 Recommendations

This study focused on identifying the risk factors and used fuzzy logic model for calculating how BIM can reduce the risk level of factors that affect project cost. As BIM is neither implemented in the case study projects form the start nor it was the requirement from the client, hence it was not easy to quantify these benefits. Therefore, quantifying the cost risks and BIM benefits in monetary terms is out of the scope of this study. For future studies, the identified risks should be integrated with project cost contingency and a Monte-carlo simulation model should be devised to substantiate the monitory benefits of BIM.

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