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Research article

A NOVEL BIM-ENABLED SOFTWARE-BASED SOLUTION FOR MITIGATING CONSTRUCTION RISK MANAGEMENT

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Abstract

This paper presents a novel Software-based solution to mitigate the most prevalent construction risks with systematic implementation of Building Information Modeling Software at the lifecycle stages of the project and provides practical recommendations for industry practitioners. The construction industry has a complex and uncertain process presenting different opportunities and challenges at various project phases. Incorporating traditional risk management methods with BIM helps identify and manage risks effectively. This research paper presents a systematic approach to implementing BIM throughout the lifecycle of an eight-story building project, from feasibility to construction, to manage major risks in each phase. The paper addresses a gap in the literature by identifying and mitigating prominent risks in the construction industry of Pakistan through BIM modeling, based on a review of 180 common risks and detailed interviews. The research methodology involved surveys and data analysis to identify and prioritize the most significant risks and suitable BIM mitigation measures. The study suggests that BIM's collaboration software resolves communication issues while Clash Detection mitigates Design-related risks before the start of construction. Simulation of Planned vs. Actual Progress and accurate Quantity Estimates achieved by BIM's estimation software contribute to the successful completion of the project. BIM and its tools have the potential to revolutionize the construction process if used as a structured risk management tool throughout the project lifecycle. The paper advises designing out most project risks in the Planning and Design phase while reserving monitoring and control for later stages as early identification and management of risks is critical for success.

1. INTRODUCTION

With the increasing complexity of construction methods and innovations in the Architecture, Engineering, and Construction (AEC) industry, risk management has become a top priority. Throughout the life cycle of a construction project, numerous risks can impact its cost, time, quality, and safety. Poor planning and scheduling, design variations, inaccurate budgeting, supplier defaults, inappropriate construction processes, and lack of communication and coordination among key parties are among the risks that can arise.[1] Building Information Modeling can play a significant role in risk management throughout the project life cycle through visualization, simulation, and improved collaboration with its various dimensions yielding results of increased productivity, quality, and accurate cost and time estimates.[2] While developed countries incorporate risk management as a separate field in the construction industry, underdeveloped countries like Pakistan often neglect it. This is due to the technical terminologies and lack of familiarity of project participants with the risk management process and its tools and techniques, which creates a significant barrier to treating it as an opportunity. This paper aims to examine the various risks associated with AEC projects and propose effective risk management strategies to mitigate their impact by the implementation of BIM.

1.1. LITERATURE REVIEW

The consequences of risks in construction projects can vary depending on their type and severity, ultimately affecting the project in various ways.[1] Efficient risk management practices are essential to interpret and manage these risks effectively. Various risk management techniques and tools have been developed over the years to control their impact.[2] However, traditional risk management approaches adopted in the construction industry are comparatively immature and lack of consistency and comprehension of RM methods.[3] Despite all the progress made for risk management in construction, Literature claimed that there are weaknesses in these techniques in giving a coherent RM framework, with failure in providing proactive collaboration among various stakeholders of the project. Many of the

Table 1. BIM based Risk Management Models

REF	FACTORS	DESCRIPTION
11	Safety risks due to design creating an unsafe work environment.	Prevention through Design (PtD); risk assessment of design elements by identifying hazards and risks and introducing design solutions meeting the design needs and creating a safe work environment for the workers through IFC files on BIM.
12	Construction process.	FMEA: visualizing the risks and predict the extent to which risks will affect construction project. Activities having assigned risk are analyzed as per impact, divided in cost and time analysis while data is put into BIM linking colors & information to Revit.
13	Mechanical failure of the construction plant, crane accidents, & Excessive deflection	Risk visualization and information management through integrating the bridge project's Risk Breakdown Structure (RBS) into 3D/4D BIM and establishing a linkage between risk data and BIM.
14	Cost and Schedule	A framework with BIM and an add-on software for full RM i.e: RiskyProject is incorporated due to its options of sensitivity analysis on risks, cost, duration, and tasks' finish times. Identified risks, through experts, were assigned to each activity and a simulation shows the durations and cost of various risks' values.
15	Labor costs, building materials, & construction machinery.	BIM-CPCSREWM: new risk early warning method, shows delayed construction processes through comparison of planned and actual progress.
16	Safety risk management	Ontology Technology with Revit: automatic risk identification and responses in prefabricated building construction, leading to efficient risk management and timely display of preventive measures.

mentioned techniques (like PERT, FMEA, Brainstorming, etc.) fulfill one function but fail to deal with other functions and hence the study suggested that they can be improved by RM workshops to bridge communication gaps.[4] BIM supports feasibility, budgeting, visualization, quality management, construction sequencing, and clash detection. BIM can also aid in safety management, risk scenario planning, and scheduling for risk identification and management. Additionally, BIM's RM tool facilitates data generation and enables multiple BIM-based tools to perform risk analysis.[1]

BIM facilitates better management, sharing, and utilization of design information, enabling stakeholders to make informed decisions in building projects. It helps in the efficient handling of on-site issues reduces risks by detecting clashes during the design phase and improves cost-estimating accuracy in procurement. BIM reduces rework in the Construction Stage by providing visual aids for planning and managing construction operations ahead of time. This improves collaboration, lowers costs, and eliminates the need for on-site inventories along with early risk detection and management while providing manufacturer standards and maintenance guidelines for clients and operators at the handover stage.[5] BIM offers a variety of Risk management features throughout the project lifecycle. Starting from the planning phase, the scope of the project is defined in BEP with deliverables and objectives which brings about project protocols for interoperability as well as milestones to achieve. Every project participant is listed in the document with their roles and responsibilities to collaborate for successful project completion.[6] BIM's safety models have also yielded positive results with integration with VR and dynamically monitoring the safety of the manufacturing process.[7] BIM has been proven to help in emergency response plans with its operation and management models integrated with risk analysis.[8] BIM modeling is used for quantity calculation and BP neural network algorithms for cost prediction to prefabricated building construction processes and improve the benefit-cost ratio.[9] The general observation shows the construction industry in Pakistan lacks awareness of risk management processes. Although risks are often addressed through personal experience and judgment, a proper RM process may not be implemented due to the associated costs and the reluctance of employers to pay for it.[10] The implementation of traditional RM processes is particularly challenging, and even in mega projects, a proper RM process is typically not followed. BIM-based technologies have suggested a variety of models to manage and mitigate risk at an early stage and a few have been discussed below in table 1.

1.2. METHODOLOGY

The methodology involved a literature review of construction risk management and BIM-based tools, followed by interviews and surveys to identify and prioritize construction project risks that could be managed or modeled with BIM. A list of 8 construction risks was finally obtained using input from professional BIM experts, utilizing the Delphi technique. Eight Risks analyzed were Inadequate project planning, Poor coordination, and Communication among various parties, Rework in the construction stage, Incomplete design, Plans of design incompatible with execution, Inaccurate quantity estimates, Collaboration and communication, and Ineffective scheduling and planning in the construction stage. A 3D BIM model was created using Revit software for an existing building in Karachi, Pakistan. The model was used to identify and mitigate relevant risks in

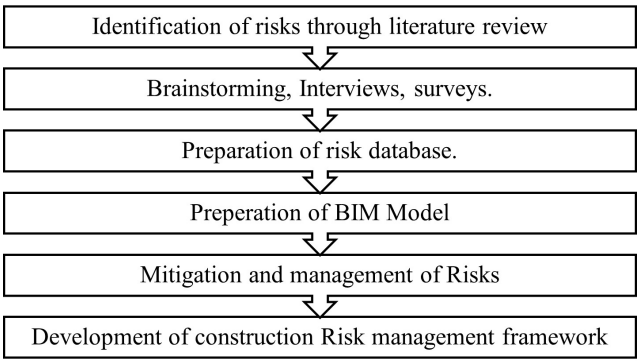

Figure 1. Methodology of study

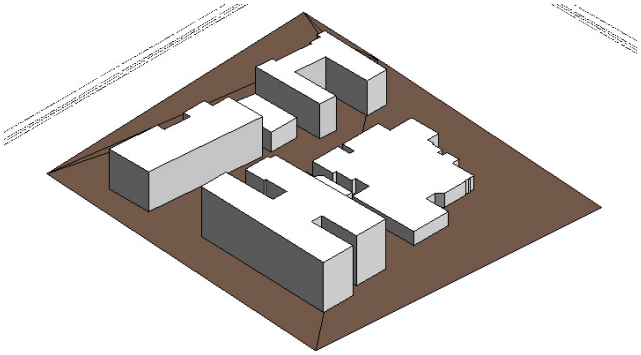

Figure 2. LOD 200 of Project Model

different project stages, based on the prioritized risk list. Finally, a systematic BIM implementation suggestion was proposed for local construction projects in Pakistan, based on the study's findings to manage risks using BIM-based tools for future construction projects in the region. Figure 1 shows a comprehensive Methodology.

2. RESULTS AND DISCUSSIONS

The study examined the use of BIM tools and techniques to manage risks that arrive in constructing a building with 6 floors, with a substantial covered area and a significant construction cost. In original construction, BIM was not utilized in any of the project's phases. To conduct the study, a 3D BIM model was created using 2D architectural and structural drawings. Additionally, 4D and 5D BIM models were created using project schedules and cost estimations, respectively. The aim was to manage risks at each stage of the project through the use of BIM-based tools and techniques.

Starting from the Conceptual phase, BIM's collaborative tools (LOD 200 and BEP) helped manage the risk of *Inadequate project planning*. The BIM execution plan template also managed the risk of *Poor coordination and Communication among various parties*. After each stage, the BEP document is updated. The project model LOD200 (Figure 2) was created, and it provided a visual representation of the project, including its area and impact on surrounding populations hence 3-D visualization improved decision-making and helped take preliminary cost estimates. For further *Communication and collaboration* that will be needed after changes in the project, the project was coordinated, collaborated on, and managed using BIM PLUS-ALLPLAN (Figure 3), which provides a visual space for communication among all project participants. Issues were generated and displayed in the project dashboard according to priority and status, as they arrived.

To reduce *Rework in the construction* stage of a project, risk mitigation models concentrate on identifying and mitigating risks as early as the Design Stage of the Project. For that purpose, three BIM tools are utilized to manage design stage risks: Clash Detection, Revit Interference Check, and Visualization. Navisworks was used to visualize and identify the missing components of the building, reducing the

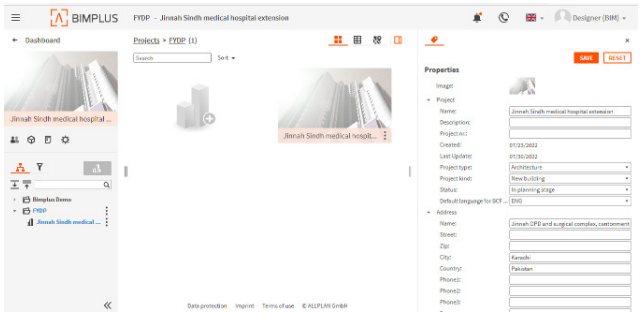

Figure 3. ALLplan Interface

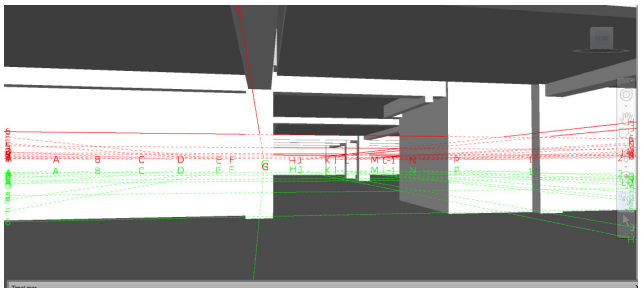

Figure 4. Walkthrough in Navisworks

risk of "*Incomplete design*" (Figure 4). A helpful tool called Revit interference check runs clash tests and creates an HTML report (Figure 6) of any issues that arise so delays due to detailed review are avoided and conflicts due to "Rework" are prevented.

Discrepancies, conflicts, or clashes between elements of a building lead to the risk of "*Plans of design incompatible with execution*". These can be removed by BIM's Clash Detection which provides identification via IFC or notice of changes in the Common Data Environment. A clash test between architectural and structural elements showed one such clash that the door was placed within the thickness of the wall as shown in Figure 5, disturbing the area of the room.

The clash was easily highlighted, quickly assigned to the project manager, and corrected. A detailed list of clash-related information lessens the possibility of designers failing to apply suggested improvements as a result of miscommu-

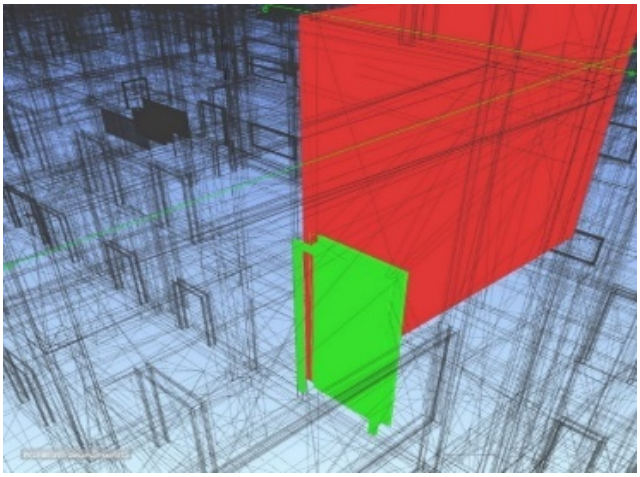

Figure 5. Clash Detected

nication. A clash report, shown in Figure 7, that could be shared with stakeholders on CDE platforms, was produced using Navisworks Manage 2021. Furthermore, BIM facilitated frequent quantity takeoff updates whenever a new design drawing was created or modified. Using the Navisworks Manage 2021 quantification tool (Figure 8) helped mitigate the risk of "*Inaccurate quantity estimates*", allowing to production of rough and accurate estimates for the project at each stage.

When submitting a bid, contractors face the risk of inflated or inaccurate cost estimates, tight project timelines, and challenges of finding exact prices for each building component. Building components of BIM available on Revit library have markets and manufacturers that manufacture them in accordance with specifications. The survey recommended the use of BIMSmith in Pakistan, while several subcontractors are also working on developing comparable BIM solutions for regional projects in the country.

As the project enters the construction phases, most risks should have been identified, assigned, and mitigated. The primary focus should now shift to risk tracking and management to promptly address any new risks that may arise. BIM has significant benefits during the construction phase, including cloud connectivity for "*Collaboration and communication*", which enables the control of risks through a common data environment. Although delays may be unpredictable, a project should be able to manage them. Therefore, the project schedule should be created in such a way that any delay in an activity will not impact the project cost or the project delivery time. The risk of "*Ineffective scheduling and planning in the construction stage*" was managed by Navisworks simulation which prepared different optimistic, pessimistic, and most probable durations in a 3D virtual environment to visually see how the project will behave between two durations if the project is delayed for any reason (Figure 9). This provided scenario-based planning of the project in a virtual environment.

Miscommunications and disputes frequently occur during the construction stage. For this purpose, the same CDE space was utilized to track the project schedule and duties given to stakeholders at various construction stages. Project documents were submitted to ALLplan and necessary RFIs or requests for changes were exchanged on the portal, Using BIMPlus AllPlan stakeholders were informed of any delay or halting of work, creating a convenient and visual communication channel for every stakeholder.

Additionally, by utilizing BIM collaboration software, project stakeholders can facilitate procurement processes by adding detailed BIM elements and components to the project model after reaching LOD 300, and subsequently

jsmu hospital Error Report (7/1/2022 8:15:08 PM)

Error message	Elements
Line is slightly off axis and may cause inaccuracies.	Lines : Model Lines : id 283497
Line is slightly off axis and may cause inaccuracies.	Lines : Model Lines : id 283532
Line is slightly off axis and may cause inaccuracies.	Lines : Model Lines : id 283621
Line is slightly off axis and may cause inaccuracies.	Lines : Model Lines : id 283656
There are identical instances in the same place. This will result in double counting in schedules.	Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 514764 Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 515299
There are identical instances in the same place. This will result in double counting in schedules.	Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 518048 Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 518521
There are identical instances in the same place. This will result in double counting in schedules.	Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 533833 Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 533845
There are identical instances in the same place. This will result in double counting in schedules.	Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 533879 Structural Framing : Concrete - Rectangular Beam : 8" X 24" : id 533885
Highlighted floors overlap.	Floors : Floor : Concrete Slab - 6" : id 348424 Floors : Floor : Concrete Slab - 6" : id 351825
Highlighted floors overlap.	Floors : Floor : Concrete Slab - 6" : id 526996 Floors : Floor : Concrete Slab - 6" : id 527787
Highlighted floors overlap.	Floors : Floor : Concrete Slab - 6" : id 527054 Floors : Floor : Concrete Slab - 7" : id 527230
Highlighted floors overlap.	Floors : Floor : Concrete Slab - 6" : id 537371 Floors : Floor : Concrete Slab - 6" : id 537434
Highlighted floors overlap.	Floors : Floor : Concrete Slab - 6" : id 537385 Floors : Floor : Concrete Slab - 7" : id 537392
Insert conflicts with joined Wall.	Walls : Basic Wall : Generic - 4" : id 445558 Windows : Fixed : 8' - Mark 28 : id 502330
Insert conflicts with joined Wall.	Walls : Basic Wall : Generic - 4" : id 445747 Windows : Fixed : 8' - Mark 29 : id 502386

Figure 6. Error Report by Revit Interference Check

AUTODESK NAVISWORKS

Clash Report

Test 2	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
	0.025m	635	635	0	0	0	0	Hard	OK

									Item 1					Item 2				
Image	Clash Name	Status	Distance	Grid Location	Description	Date Found	Assigned To	Clash Point	Item ID	Layer	Path	Item Name	Item Type	Item ID	Layer	Path	Item Name	Item Type
	Clash1	New	-0.699	C-3 : Ground Floor	Hard	2022/7/30 17:11		x:-0.374, y:-0.825, z:4.133	Element ID: 393550	Ground Floor	File > EDITED VERSION OF JSMU my.nwc > Ground Floor > Walls > Basic Wall > Generic - 6" > Basic Wall > 3. white paint	3. white paint	Solid	Element ID: 516175	BEAM	File > EDITED VERSION OF JSMU my.nwc > BEAM > Structural Framing > Concrete - Rectangular Beam > 10" X 36" > Concrete - Rectangular Beam > 3. white paint	3. white paint	Solid

Figure 7. Clash Report

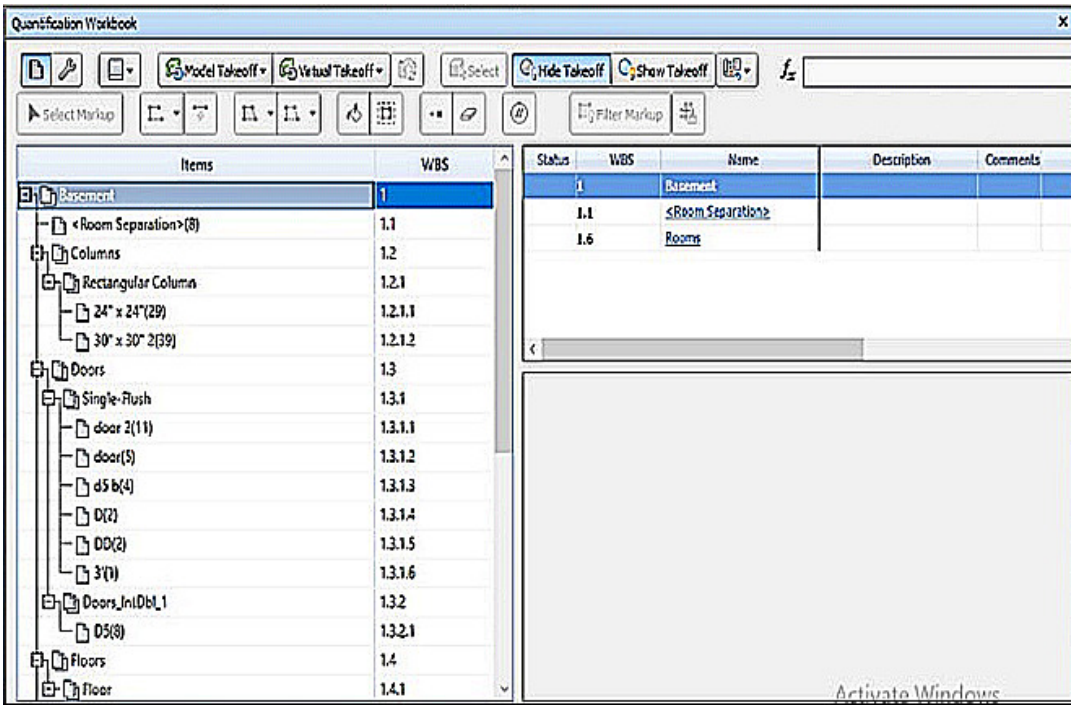

Figure 8. Interface of Navisworks Manage Quantification

uploading the models in the IFC format for seamless integration with other tools and platforms. It provides access to building element specifications and designs a communication interface to meet the needs of the client. The results of the survey showed that BIM's Construction-Operations Building information exchange (COBIE) documents are very helpful for project handover as they transmit facility asset information for spaces and equipment and help make space management for the facility manager simpler.

As shown in Figure 10, this study emphasizes using Building Information Modeling tools such as Common Data Environment, Clash Detection, and Quantification using Navisworks, and its documents like COBIE and BEP for systematic Risk Management in the Construction Industry of Pakistan. It is an emerging development and provides risk identification, analysis and control on a single shared workplace from the Conceptual to Facility Management phase of the project. By using BIM, the construction industry in Pakistan can achieve better financial outcomes and facilitate

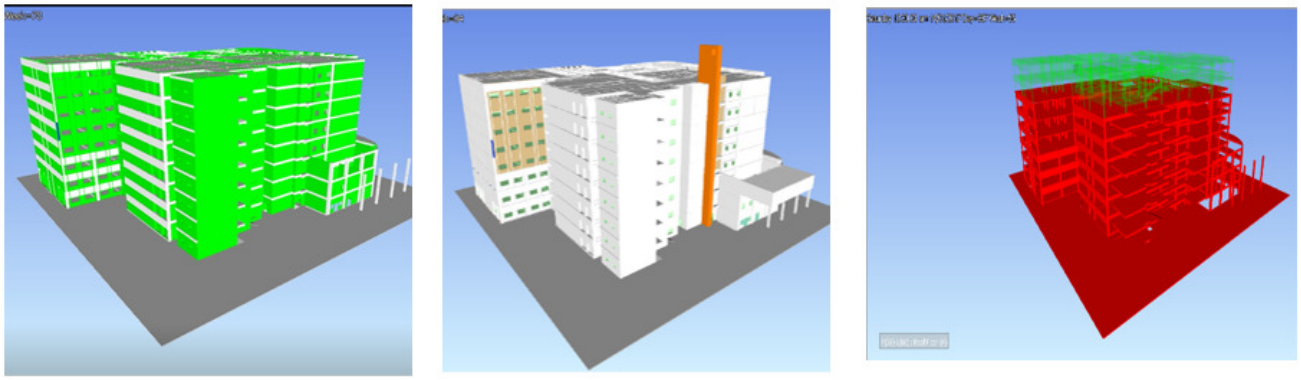

Figure 9. Completed Structure Work Vs Completed Project Simulation Vs Delay in Project

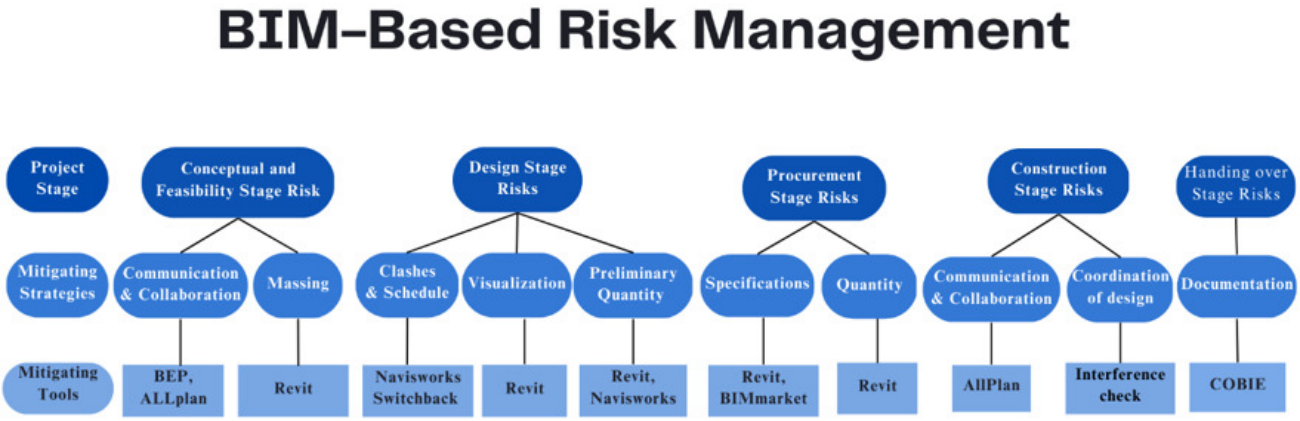

Figure 10. BIM Based Risk Management

economic growth. Overall, BIM has the potential to revolutionize risk management in the AEC sector, making projects more sustainable and successful.

3. CONCLUSIONS

To conclude, the AEC sector is exploring the use of BIM and related digital technologies for effective risk management in construction projects. Traditional risk management methods have limitations, but when combined with BIM, risks can be successfully mitigated throughout the project life cycle. This research project aims to assist construction project managers and clients in mitigating risks with the application of BIM, providing benefits such as early identification and mitigation of risks. The interviews with BIM managers suggested that a proper systematic BIM integration from the development phase of the project with an integrated design process can manage the majority of risks identified in the early stages of the project. Starting from adopting a level of development and involving each stakeholder in the design process majority of the risks can be mitigated before the construction stage arises. While for construction only controlling and monitoring of such risks will be required.

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