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Building information modeling as a risk transformer: An evolutionary insight into the project uncertainty

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ABSTRACT

Building information modeling (BIM) is a promising technology for the construction sector, as it addresses multiple risks, supports decision-making and enhances value. However, its technological and contractual novelties introduce some new risks. To observe the BIM-driven risk transformation, this paper performs a thorough analysis involving international experts and practitioners. Data is collected in the form of open-ended interviews and typeset questionnaire along with case studies of running projects. Results reveal that BIM eliminates a majority of significant risks. Further, the findings fuel a new research problem; the lack of a dedicated BIM plugin for risk management. Responding to it, a theoretical framework is developed to automate the risk management process and improve overall project management practice. It is concluded that construction projects can greatly benefit from an automated risk management system and investment in developing a dedicated plugin is recommended, ensuring an effective penetration of BIM in the construction industry.

1. Introduction

Construction projects are unique in their nature [1], their process is complex from beginning to end, and they are characterized by uncertainty [2]. Since uncertainty and risk are unavoidable in such projects, they should be managed, minimized, accepted, shared and transferred, but should not be ignored [3]. The concept of risk and its management is not new. Various studies have maintained that proper risk management is advantageous to construction projects and industry [4]. Risk management is generally considered a critical part in the overall process of construction management and is practiced using tools like spreadsheets, brainstorming, strengths-weaknesses-opportunities-threats (SWOT) analysis [5,6], and risk registers [7,8] to name a few.

Despite the use of such systematic tools and techniques, information on the existence of risk has remained challenging owing to its evolving, subjective, emerging, nonlinear and behavioral characteristics which result in the escalated criticality of risk management [9–11]. Also, the traditional approaches are usually manual, with marginal reliance on software solutions and automation [12]. The majority of analysis is based on mathematical calculations and expert judgments. Thus, the practice of such a manual system for risk appraisals throughout the project progress reduces overall productivity [13]. This lack of information, it's automation and modeling in construction projects enhances the uncertainties, fueling the quantum and intensity of risk, paving a way towards project failure [14].

With a rapid advancement in information and communications technologies (ICT), Building Information Modeling (BIM) has emerged as an information source and a core data generator to support the decision-making [13,15]. Inputting huge amounts of data helps BIM to see through various complexities and uncertainties [16–18]. Risk management in construction projects applying BIM is highly significant [13], as the implementation of BIM introduces a major sway on standard level of risks due to the emergence of newer opportunities [18,19]. The application of BIM eliminates some fundamental risks such as those related to design and construction drawings [17,20–22]. It also assists designers by removing clashes, improving visualization and prefabrication process [17,23,24], and modeling sustainability simulations [25,26]. BIM also improves communication between project stakeholders [17,27], enhances coordination, and reduces the risk of variation and reworks. Further, it reduces safety risks by developing site safety plans and layouts [17,19]. The list of various advantages of BIM can be further enhanced by its risk mitigation capability [17,18].

Though positive, innovation in construction has its cost in the form of rapidity, uncertainty and lack of standardization [28–31]. This

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innovation comes in many forms, such as technical [32], contractual [33], managerial or organizational [34–36]. An example in this context is the modular construction technique which is prone to trial and error strategies for dimensional and geometric variability [37]. Similarly, cost and effort of data acquisition are crucial in sensor technologies and robotic applications in construction [32] which are further exasperated by the limited mobility, weight, size and even accuracy of automated construction systems [38]. Based on the similar line of argument on innovation [29], BIM brings some new risks of its own [18,39,40]. These include risks of liability, copyright and ownership due to weakening concept of responsibility [29,39–41], un-generalized impacts on individual projects [42], and numerous other technical, financial and legal risks [28–31,39,40].

Despite these new risks due to its implementation, BIM has the capability to reduce the intensity of threats [13,16–19], making the tradeoff between elimination of existing risks and formation of newer ones positive, with a greater portion of them being opportunities. In contrast to computer-aided design (CAD), where negative risks outweighed the opportunities [43], BIM is a better risk transfer system. Regardless of the significance of new risk introduced by BIM, a proactive approach is needed to further enhance its value proposition [18,44].

This proactive approach comes in the form of 'BIM-based risk management', which is an emerging process in the construction industry with a number of new openings for further development. According to Araszkiewicz [19], there does not exist a proper analysis of systematic integration of various areas of construction project management in BIM processes, procedures and methods, and techniques of risk management. Further, except for some theoretical attempt [45], the integration of traditional risk management with new technologies is largely missing [13]. The evolution of pre- and post-BIM risk, in the form of elimination and transformation of existing risks, and creation of newer ones, is yet to be investigated.

To fill these research gaps, the current study examines the performance of risk management in both traditional and BIM systems. In doing so, the evolution of risk is traced using published works, expert opinion and case study based data acquisition through systematic literature review, BIM practitioners and institutional buildings, respectively. The risk transformation helps practitioners in appreciating the value proposition of BIM in the context of project risk management. This paves the way for the development and integration of dedicated tools in BIM environment for an enhanced productivity.

2. Literature review

Since an attempt is made to study the evolution of project risk in the face of information systems, specifically BIM, the reviewed literature encompasses the major areas of risk management and ICT based information modeling solutions in the construction sector.

2.1. Project risk management

Risk is an uncertainty that impacts the project objectives [46]. Every activity in a construction project involves risks of varying degree which need to be managed to keep the project under control [3]. According to Frimpong et al. [47], a successful project is characterized by its achievement of a set objectives and goals with regard to its technical aspects, and time and budget constraints. But it is not so simple in construction projects; risk can negatively influence the project success by diminishing its performance, resulting in cost and time overruns, and quality decline, causing the failure of the project [48–50].

A number of studies have discussed the impact of risk on construction projects in terms of success parameters. For example, in Saudi Arabia, 70% of projects suffer time and cost overruns due to 73 multiple risk factors [51]. Similarly, Odeyinka and Yusif [52] found that 7 out of 10 Nigerian construction projects suffer delays and cost overruns due to various uncertainties. Also, Mansfield et al. [53] identified 16 major risk factors behind project failure. Frimpong et al. [47] identified causes of project delay and cost overrun in Ghana based on 26 critical uncertain factors. They found that payment delays, stakeholder management, material procurement, inadequate technical performance and price escalation are the major factors. Also, Sambasivan and Soon [54] identified 10 significant risk factors causing delays in construction projects and quantified that almost 17% public projects in Malaysia fail to meet their timeline due to such factors. These studies assert the criticality of risk management process for achieving project success in all of its dimensions including cost, time, quality of work, safety and sustainability [1,55].

Risk management is a holistic process of identifying, analyzing and responding to project risks [56,57]. Identification of risk factors, which may positively or negatively influence project outcomes, is the first and most crucial part of an effective risk management process [29]. Further, after the identification of potentially influencing factors, they are analyzed for categorization based on their criticality [2]. According to ISO [3] there are a number of techniques for identification, analysis and evaluation of risk. The assessment techniques can be classified into qualitative and quantitative categories, with some semi-quantitative techniques [29]. These techniques are supported by various tools such as checklists, spreadsheets, Delphi method, SWOT analysis [5,6], risk ranking, risk registers [7,8], environmental risk assessment, row tie analysis and risk incidences to name a few [13]. However, the subjective and nonlinear nature of risk, and limited statistical information obtained from these techniques, makes them inefficient in practice [58].

To make matters worse, these analyses are manually carried out with marginal dependence on ICT tools. Thaheem and De Marco [12] found that only 21% of global construction industry uses risk assessment software. The traditional manual risk assessment practices are largely based on statistical and mathematical calculations, and expert judgments. Similar is the case with the decision-making. This leads to a decrease in efficiency in a real environment, especially in the developmental phases of projects where it is essential to properly keep updated risk registers [13]. Likewise, the construction projects experience a proprietary transformation from planning to operating phases. In this context, the onus of responsibility shifts from one party to another during the project progression. It is tantamount to an assembly line where every operative completes their job and gets contractually entitled to leave from the project. Though this is an efficient system in terms of optimum utilization of resources, it results in loss of information about any occurred risk and its mitigation strategy if not recorded properly or shared with other participants [59]. Ideally, most of the risks are identified during the planning phase and the remaining ones during execution and succeeding phases. But the transactional nature of construction projects leads to a lack of information and ineffective communication which fuels uncertainties and triggers project failure [13].

It is evident from the literature that this lack of automation and information management practices is at the core of underperformance of risk management in the construction industry. Any construction business will need to incorporate better ICT tools for explicitly or implicitly improving the state of project management.

2.2. Role of ICT in risk management – A view on BIM

With rapid advancement in ICT, such as CAD, BIM [17–19,29], virtual [60,61] and augmented realities [62], risk management has been strengthened. These tools indirectly support decision-making in construction projects. BIM is defined as "*a shared digital representation of a built object to facilitate design, construction and operation processes to form a reliable basis for decisions*" [63]. It has emerged as a recent development in ICT for the construction industry. It is an information and data generation source aimed at facilitating critical decision-making.

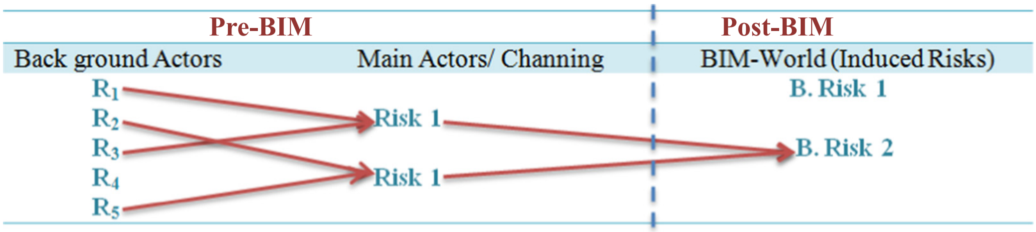


Fig. 1. Risk transformation due to BIM implementation in construction projects.

The data generation feature of BIM is not only unique but rare as well. Forsythe [64] and Teizer et al. [65] compared the reactive systems, such as virtual reality (VR), 4D CAD and geographic information system (GIS), and proactive technologies, such as BIM, for their real-time data collection and processing capabilities and found that BIM can be used as a systematic information management tool in the development process and generate core data to allow other BIM-related tools for various analyses, including those of risk and uncertainty. Due to its automatic rule checking and large plugin support in the form of knowledge-based systems, and reactive and proactive IT-based safety systems [66], BIM emerges as a data generator [13]. BIM has further established its value in construction industry by augmenting the 3D visualization and coordination [40], eliminating object clashes [39,67] and providing a collaborative work environment [23].

Considering the subjective, emerging, behavioral and nonlinear characteristics of risk, where experiential information would be vital, a substantial and flexibly retrievable databank of previous risks is a precondition for effective risk management. It can benefit even more from a thorough identification by considering complete project life cycle [68]. BIM, with the potential to capture all project phases, has been performing such roles. It is one of the most discussed and published topics of recent times, promising to achieve multiple objectives by enhancing communication and collaboration between participants throughout a project's life cycle [18,69]. BIM, as a parametric and digitized information system, enables practitioners to have a better project understanding by 3D coordination [40], constructability reviews [70], 4D schedule simulation [71], 5D estimation through automatic quantity takeoff [40,71], project progress curves [72], procurement management and integration with subcontractors [70], prefabrication, facility management [73], quality control and spatial management [74], and various design analyses including structural, lighting, HVAC and energy [39,70,75,76].

With such potential, BIM has proved beneficial for construction projects in multiple aspects. Various success stories are reported in this context. According to Building and Construction Productivity Partnership [77], BIM was implemented in a prestigious project of the New Zealand government with an objective to complete it within schedule and 80% reduced operational cost. Owing to the tough timeline, 3D coordination, redundancy avoidance and design authoring were required. As a result of implementing BIM, communication and collaboration was improved, controlling project risks and achieving set objectives. The same practices were applied on the construction of a campus hall measuring 125,000 sq. ft. at a major university in Massachusetts, USA. Owing to a large presence of students, it was essential that routine campus activities continue uninterrupted. Thus, the objectives were spatial, logistics and safety risk management. BIM helped in achieving all these objectives with no major accident and successfully addressing the safety concerns [78]. A detailed investigation at the Stanford University, covering 32 projects, found that with its implementation, BIM achieved about 40% elimination of un-budgeted changes, 80% reduction in time for cost estimation, 10% saving of overall contract value due to clash detection and 7% reduction in project time [79].

2.3. *Effect of BIM on risk and its management*

Since construction projects incorporating BIM are extremely prominent and involve additional sums of money [29], they become crucial in terms of reputation and resource consumption making concerns of risk and its management even more important. With BIM as an innovation in the construction industry, some major transferal of standard risk level occurs [13,18]. According to Eastman et al. [17], "*a detailed BIM model is a risk mitigation tool*". Thus, BIM brings opportunities and considers risk in a positive way by reducing the uncertainties in design and enhancing communication and collaboration [16]. A detailed bibliometric analysis of BIM literature published between 2005 and 2015 reveals that various features of this technology can help improve the barriers of visualization-based risk identification and real-time communication as well as overall risk management [80]. In addition, the risk of automation, especially related to fabrication, is also addressed [17]. However, research on integration of BIM with risk management is limited [13,19]. Zou et al. [45], in their seminal study, have proposed a theoretical framework to develop a tailored risk breakdown structure (RBS) for bridge construction projects and a conceptual model for the linkage between the RBS and BIM. Another such effort has focused on construction personnel safety with the help of automatic extraction of safety information from a knowledge-based database [13].

While addressing known issues, BIM introduces its own set of concerns and risks into the project [28,31,39,81,82]. Researchers have identified some risks of such nature in financial, legal, technical, managerial and environmental categories [28–31,39,40]. The risk transformation due to BIM implementation can be synthesized in a general form as exhibited in Fig. 1 where individual risk factors, aggregated into various risk categories, are seen to evolve in the post-BIM scenario. Along with it, some old factors are entirely eliminated, such as R_4, and some new ones are introduced, such as B. Risk 1.

This general concept can be exemplified such as a client's demand of project completion may result into unrealistically tight schedule [83] which, as a background actor, may feed into the main risk of poor quality of construction [13,16–19]. The 4D and 5D simulations of BIM along with visualization and better communication helps eliminate this risk altogether [17]. In another example, the main risk of unavailability of technical professionals and managers in a pre-BIM scenario [84] results in additional initial costs for training and asset acquisition [29,30].

It can be seen that innovation brings new challenges, but the risk of implementing BIM is far less than that of CAD in construction projects [14]. However, the actual evolution of risk due to BIM is not reported in the literature. It may be argued that BIM subtly addresses a number of risks but the real value addition due to this transformative technology in the realm of risk management needs to be identified and quantified in order to justify its major capital investment demand. Since risks may cause substantial financial losses, if the value due to BIM can be quantified, its cost can be traded off with the potential losses. This will support enterprise-level decision-making for adopting BIM in the construction industry.

Table 1
Description of case study buildings.

Case study	Project name	Covered area	Tendered amount (million)	Purpose	Interview respondents
1	Central information resource centre	40, 927.5 ft^2	PKR 142 (US $ 1.42)	University library; consultation and study rooms	4 (2 client/PM; 2 contractor)
2	Multistory commercial building	383,000.0 ft^2	PKR 1539 (US $ 15.39)	Government offices; commercial and real estate property	4 (1 client; 1 consultant; 2 contractor)

3. Research methodology

Aiming to achieve the said objectives and bridge the identified research gaps, a comprehensive research methodology consisting of five major phases was adopted. In the first phase, crucial risk factors for general construction projects were identified from the published literature. In total, 16 unique risk taxonomies were consulted to obtain a total of 144 risk factors. However, owing to overlapping and duplication, these risks were reviewed and 94 factors were shortlisted as a result. Further, content analysis was performed to assess the quantitative and qualitative significance in order to screen out the least important factors [85]. The quantitative score was based on the frequency of appearance in literature and qualitative score on the described level of impact which was subjectively assessed by the authors. Further, to improve the contextualization, local industry experts were involved. In doing so, a systematic literature review technique was adopted to seek expert opinion on the importance of identified risk factors [86].

A total of seven construction practitioners having an average experience of over 32 years (σ = 9.7) were engaged to screen the shortlisted 94 risks as per the local context. Their opinion was aggregated in the form of a frequency score. The combined score consisted of literature as well as practitioner scores. It is pertinent to mention that the construction industry of Pakistan is in a developing state [87–89], therefore the state of risk presented in international literature might not fully reflect the intricacies of a developing industry. Thus, the scores from the streams of literature and practitioners might warrant different treatment. However, the exact weighting ranges are not documented anywhere in the literature, mostly due to contextualized decision-making. This allowed for improvisation based on an evidential reasoning to test and propose the decision weights using simple additive weighting method.

Different weighting ratios of 50/50, 70/30 and 80/20 to field experts and the literature respectively were statically tested using one-way ANOVA and rank correlation. The *p*-value of 0.9 and correlation values ranging between 0.7 and 0.9 suggest a statistically non-significant difference between various decision weight combinations. However, giving due consideration to local experts, 70/30 weighting split was used to select 32 major risks based on over 60% combined significance to encompass maximum influence.

In the second phase, risks induced due to BIM implementation in construction projects were assessed. Initially, a content analysis was performed through a review of published literature to identify 34 risk factors. Afterward, the identified risks were analyzed in terms of their probability and impact using the basic risk quantification form of P x I [90] which is crucial to their management [57]. For this data collection, selection of appropriate experts was challenging due to a slow adoption of BIM and few relevant experts in the local construction industry [91–93]. Therefore, an international survey was conducted to increase the reliability and representativeness. The respondents of this survey were BIM practitioners with hands-on experience. To obtain suitable and coherent data, great care was taken by evaluating the potential respondents' profiles available through LinkedIn® and other professional networks. In doing so, their professional experience of BIM, successful implementation and number of projects were considered. As a result, over 500 professionals spread all over the world were selected for the survey. Before directing the questionnaire, an invitation email was sent and only after a positive response, the link to an online questionnaire developed in Typeform® was forwarded. The survey was conducted between the months of September–December 2016 and, in result, 110 responses were collected from 33 different countries, giving a 20% response rate. The survey questionnaire sent to these respondents was divided into two major sections; section one containing the demographic and professional information of respondents and details of BIM tools in use. Section two contained BIM-influenced risks to be assessed in terms of probability and impact on a 5-point Likert scale (1 = very low, 2 = low, 3 = average, 4 = high, 5 = very high). Statistical tests were then performed to rank the most crucial risks introduced due to BIM implementation in construction projects [28–31,39,40].

After assessing the general and BIM-specific construction risks, it was deemed necessary to investigate their culmination on a real-life project. For this purpose, risk registers in pre- and post-BIM contexts were required to act as input for further analysis. In this regard, case studies of two under construction projects, whose details are given in Table 1, were selected in the third phase of research. Both buildings are government-funded projects managed by publicly owned subsidiaries acting as client/PM consultant.

The data was obtained from the corresponding institutions containing drawings (architectural, structural, MEP and HVAC), contract documents, specifications (BOQs, cost details) and work schedules (activities list) to be used as standards for further process. In order to develop pre-BIM risk register in the form of risk breakdown matrix (RBM) [94], project stakeholders were engaged to collect data on the probability and impact of risks identified in the first phase. During this data collection stage, interviews were conducted using various project scenarios over the shortlisted risks and respondents were asked to assess their effect on the project activities on a 5-point Likert scale (1 = very low, 2 = low, 3 = average, 4 = high, 5 = very high).

Subsequently, tender drawings were used to develop BIM models which were to act as a vehicle for developing post-BIM risk register. Architectural, structural and MEP models were developed in Autodesk Revit® and other supporting tools at the level of development (LOD) of 300. These models were then integrated, analyzed and detected for any clashes using Autodesk Navisworks®. In order to develop post-BIM risk register, the data obtained on probability and impact during the second phase was used for finding the most crucial risks after BIM implementation. Not only were the crucial risks assessed, their mitigation strategies are also proposed. For this purpose, a total of 5 international experts belonging to the construction industry and academia were interviewed to suggest befitting strategies to manage critical risks.

Furthermore, the pre- and post-BIM evolution of risk, which was performed in the fourth phase, was studied in detail. The identified risks from the first and second phases were treated in a causal form to investigate the transformation through a qualitative analysis. Along with the selected literature, both field and academic experts were involved to validate the hypothesized transformation. After detailed data collection and preparation, the overall analysis was carried out in the fifth phase. Along with qualitative assessment, various statistical analyses such as Spearman's rank correlation and ANOVA were carried out. On the basis of these analyses, results are presented, discussions are made and conclusions are drawn. Since this research implicitly investigates the state of automation in terms of project risk management,

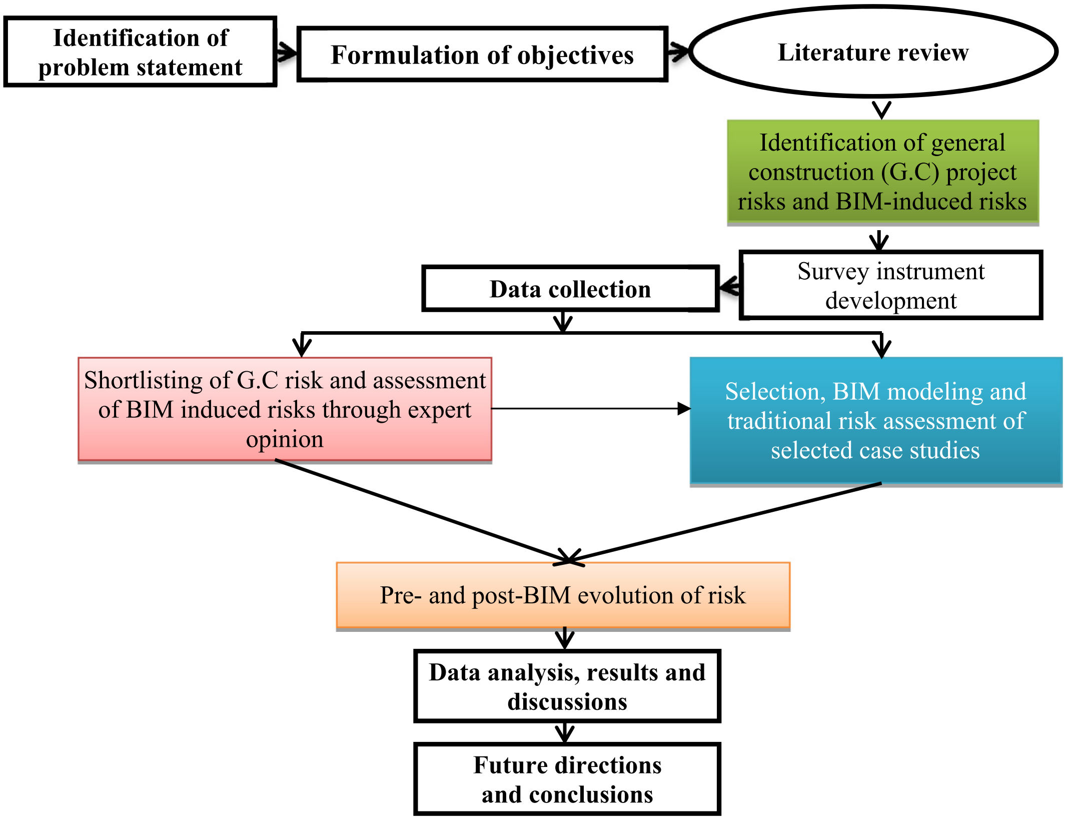


Fig. 2. Research methodology roadmap.

it was considered appropriate to propose a theoretical BIM integrated risk management framework which may act as an impetus for further research and development to enhance the value addition due to BIM. The roadmap of overall methodology is graphically presented in Fig. 2.

4. Results and analysis

In the first phase, using 16 risk taxonomies, 32 crucial risks were shortlisted based on a weighting split of 70/30 between expert and literature scores with a combined significance of 60%. The details of shortlisted risks along with their ranking and selected references are shown in Table 2 with cumulative normalized score ranging from 0.03367 to 0.6883.

In the identified risks, the top 5 risks, having normalized individual scores between 0.036 and 0.028 and cumulative scores between 0.036 and 0.159, are considered most important by field and research experts. Risk factor "*variations by the client* (*VOs*)/*change orders and reworks*", with the highest impact, represents the most detrimental effect in terms of cost, time, quality and environmental sustainability of construction projects. Studies show that the client has a major role to play in this context and this risk is usually triggered either due to a change of mind and misinterpretation by client or incomplete project briefs [1,54,83,95,96]. The second most important risk is related to late payments resulting from multiple other risks, such as variations (1st rank), project funding issues (3rd rank) and claims. Both developing and developed construction industries face this risk and projects are affected in all of their phases [1,54,83,84,95,98]. Similarly, the other three risks are project funding problems (0.101223), major disputes and negotiations (0.13099), and slow decision-making by project participants (0.15991), resulting from unsuitable planning and forecasting, VOs (1st rank), insufficient project briefs, and lack of coordination, communication and collaboration between stakeholders (7th rank) [1,51,54,84,101]. It is evident that major risks assume top positions due to a complex interaction not only between them and the project activities but also with other risks. This demonstrates a classic recurrent evolution in project risks [104]. Either by reducing or eliminating the main actors of this causation chain, the overall interconnections and their effects can be modified [105].

During the second phase, the 34 BIM-induced risks were assessed by 110 international respondents from 33 countries. Statistical analyses were carried out for probability and impact values by calculating mode, median and standard deviation to find the spread of assessed P and I values. Owing to the use of ordinal Likert scale, mode values were used for calculating the significance of risk, as shown in Table 3. Then, using discrete P and I values, risks were assessed on a PI-matrix and categorized into Low, Medium and High ranges. Standard score limits for Low (1–4), Medium (5–10) and High (12–25) are used [56]. A total of 12 risks were assessed and ranked as High, whereas 22 were assessed as Medium with no Low-level risk, as shown in Fig. 3.

Illustrated in Table 3, risk values are from 20 to 09 with the major spread of data in medium level risk. The highest ranked risk "*lack of BIM knowledge*" is quite established in the literature and has been criticized as a major barrier to BIM adoption in the construction industry. According to Ku and Taiebat [30], for a successful implementation of BIM in construction projects, the practitioners have to have knowledge of model specification, validation, access management, version control and interoperability. They further concluded that the BIM knowledge areas like constructability and visualization are fast in demand for the construction graduates. Owing to this, many studies have stressed the enhancement of BIM knowledge by introducing structured courses and integrating existing construction courses with BIM [81,106].

The second most significant risk deals with the lack of standard contract agreement. Ku and Taiebat [30] identified 31 barriers to adoption of BIM and found that the lack of suitable contractual instruments is a major impediment. Other studies have also shown that the contractual and legal issues occur with the emergence of risk like

Table 2
Assessed traditional construction risks.

Rank	Description of risk	Normalized score	Cumulative score	Selected references
1	Variations by the client/change orders/rework	0.036799847	0.036799847	[1,54,83,95,96]
2	Payment delays	0.034649207	0.071449054	[1,54,83,84,95,97,98]
3	Project funding problems	0.029774422	0.101223475	[1,51,84,97,99]
4	Major disputes and negotiations	0.029774422	0.130997897	[54,100]
5	Slow decision-making	0.028914166	0.159912063	[54,84,101]
6	Contract breach by client/contractor	0.028053909	0.187965972	[54,95]
7	Lack of coordination between project participants/stakeholders	0.026811317	0.214777289	[54,84]
8	Delay in contractor's claims settlements	0.024373925	0.239151214	[84]
9	Unrealistic program scheduling/delay in completion	0.024230549	0.263381763	[1,96,97]
10	Slow response by the consultant engineer regarding testing and inspection	0.024230549	0.287612311	[84,99]
11	Contractor financial failure	0.023800421	0.311412732	[54,95]
12	Inadequate risk management plan	0.023800421	0.335213152	[54]
13	Slow response by the consultant engineer to contractor inquiries	0.023657045	0.358870197	[84]
14	Mistakes and delays in producing design documents	0.023657045	0.382527241	[99]
15	Material procurement by client/contractor	0.023370292	0.405897534	[102]
16	Excessive approval procedures in administrative/government departments	0.022557828	0.428455362	[101]
17	Conflict between actual quantities and contract quantities	0.020550564	0.449005926	[101]
18	Corruption	0.020407188	0.469413114	[99]
19	Material changes in type and specifications during construction	0.020407188	0.489820302	[51,97,99]
20	Incomplete or inaccurate cost estimate	0.016583827	0.506404129	[101]
21	Inadequate or insufficient site information (soil test and survey report)	0.016153699	0.522557828	[96]
22	Mistakes and discrepancies in contract document	0.016153699	0.538711527	[54]
23	Frequent change of subcontractors	0.016010323	0.554721851	[99]
24	Tight project schedule	0.015771363	0.570493214	[96]
25	Poor quality of construction	0.015771363	0.586264577	[97,103]
26	Cost overrun	0.015723571	0.601988148	[103]
27	Unpredicted technical problems in construction	0.015723571	0.617711719	[99]
28	Design errors	0.014911107	0.632622825	[97,99,101]
29	Lack of experience of contractor	0.014815523	0.647438348	[54]
30	Site access delays	0.014480979	0.661919327	[99]
31	Inappropriate construction methods	0.013620723	0.67554005	[99]
32	Preparation and approval of shop drawings	0.012760466	0.688300516	[51]

Table 3
Assessed BIM-induced risks.

Risk Code	Description	Probability	Impact	Risk value	Selected references
B. Risk 1	Lack of BIM knowledge	4	5	20	[29,30]
B. Risk 2	Lack of standard contract agreements	4	4	16	[28–30,82,108]
B. Risk 3	Inadequate project experience	3	4	12	[29,30]
B. Risk 4	Unclear business values	4	3	12	[29]
B. Risk 5	Management process (change difficulties) - lack of understanding from 2D to 3D systems	4	3	12	[29]
B. Risk 6	Reluctance to share open information	4	3	12	[29]
B. Risk 7	Lack of integration of traditional 2D work flows with 3D tools - transition difficulties	4	3	12	[29]
B. Risk 8	Technical personnel - lack of familiarity with BIM	4	3	12	[29,30]
B. Risk 9	Considerable amount of time required to become familiar with software operation	4	3	12	[29]
B. Risk 10	Rise in initial short-term costs (finances) - training, design reviews, hardware and software acquisition	4	3	12	[29,109]
B. Risk 11	No clear dispute-settlement mechanisms	4	3	12	[29,31,107,108]
B. Risk 12	Risk of responsibility of entering correct data - making up-to-date model	3	4	12	[18,28,29,39,82]
B. Risk 13	Un generalized impact of BIM on construction projects	3	3	9	[18,42,110]
B. Risk 14	Risk of innovation	3	3	9	[42]
B. Risk 15	Lack of software compatibility	3	3	9	[29,39,107]
B. Risk 16	Data integration issues	3	3	9	[14,29,39,82]
B. Risk 17	Model management issues during updating versions	3	3	9	[29,81,82]
B. Risk 18	Accuracy of entered data	3	3	9	[29,82,107]
B. Risk 19	Risk of security - data knowledge to be leaked	3	3	9	[29]
B. Risk 20	Inefficient data interoperability	3	3	9	[14,29,107]
B. Risk 21	Risk of data loss - as digital system	3	3	9	[29]
B. Risk 22	Reluctance of other stakeholders	3	3	9	[30,39]
B. Risk 23	Shift of liability among project participants with respect to management process	3	3	9	[29]
B. Risk 24	Inadequate top management commitment	3	3	9	[29,30,39]
B. Risk 25	Shift of liability among project participants with respect to workflow transitions management	3	3	9	[29]
B. Risk 26	Acceptance of BIM by existing staff	3	3	9	[29]
B. Risk 27	Increase in short-term workload - establishing BIM libraries	3	3	9	[29]
B. Risk 28	Training of existing staff - learning of new techniques	3	3	9	[29,30]
B. Risk 29	Additional financial expenses - legal disputes, software updating, etc.	3	3	9	[29,30,109]
B. Risk 30	Lack of BIM standards - no clear product delivery and acceptance of model criteria	3	3	9	[28,29,82,108]
B. Risk 31	Unclear coverage of insurance policy for BIM system	3	3	9	[18,40,82,107,108]
B. Risk 32	Limited warranties and disclaimers of liability by designer (BIM system)	3	3	9	[40,107]
B. Risk 33	Intellectual property ownership - copyrights issue	3	3	9	[18,29,82,108,111]
B. Risk 34	Liability issues (lack of operating BIM/errors)	3	3	9	[28,29,82]

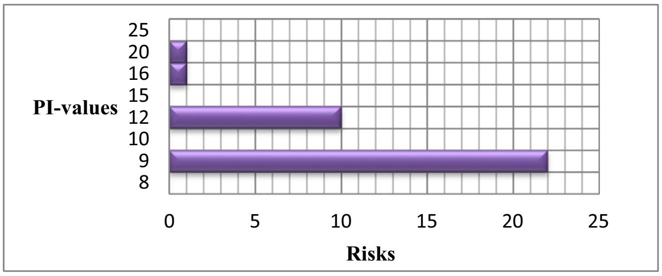


Fig. 3. Risk ranking using PI-model.

copyright and ownership (33rd rank), responsibility, liability and related issues (32nd, 34th also 23rd and 25th ranks) [82,107]. Similarly, Rosenberg [31] suggested that the integrated notion of BIM blurs the sense of responsibility resulting in the elevated levels of risk and liability issues. To address these concerns, studies suggest that BIM implementation must be done under clear contract clauses [29], outlining the details of copyrights and responsibility issues [31], offering provisions for limited warranties and disclaimers of liability by designers, and adopting integrated project delivery (IPD) [82].

It can be seen that a total of 10 BIM-induced risks, identified as B. Risk 3 to B. Risk 12, were assessed as High with a score of 12. According to Chien et al. [29], lack of organizational risk maturity in the form of inadequate project experience, unclear business values and non-streamlined impact of BIM on construction projects can be reduced by conducting proper project feasibilities and determining the impact of technology in terms of profit for the business. On the other hand, a proactive strategy would be to run a pilot project before doing an organization-wide BIM launching. Whereas, issues of change management and trust deficit, as coded in B. Risk 5 to B. Risk 7, can be reduced by a controlled implementation in a hierarchal form, and avoided by hiring BIM professionals and service providers [112]. Further, human resources related B. Risk 8 to B. Risk 10 can be reduced by reassigning people and inducting experts into teams. B. Risk 11 to B. Risk 12, which are contractual in nature, can be reduced or avoided by putting clear contract clauses [29], which can be achieved by eliminating B. Risk 2 as discussed before. A causal chain between risks is evident in this case as well.

During the third phase, the traditional risk management was performed on both case studies, and their RBMs were developed using the risks assessed in the first phase, and work schedules and detailed interviews obtained through the project participants. A total of two RBMs involving client/PM consultant and contractor were developed for the individual project. Each stakeholder was asked to score the risk and identify the activities influenced by that particular risk as shown in Table 4. It is imperative to mention that a risk-longitudinal analysis is tricky to carry out between case studies owing to the unique nature of projects, their stakeholders, the organizational maturity and capacity, the level of preparedness, and physical and other conditions. For example, the funding problems are seriously highlighted in the second case study and not in the first. Similarly, design errors are highlighted in the first case study and not in the second.

Focusing on individual analysis, in the case study of Central Information Resource Centre, which consists of 47 activities of work schedule, 32 risks were assessed. The average risk values for client/PM range between 0 and 16 and for contractor between 0 and 20. It is interesting to note that the average accumulative risk score for client/PM amounts to about 81 and that for contractor is 72. Since this project is awarded on the design-bid-build basis, the major risk is shouldered by the client [113].

Apart from risk score, the influence of a certain risk on project activities was also assessed. Both stakeholders report a different amount of influence owing to a difference in their contractual obligations. Therefore, statistical analyses were performed to check the level of difference through variance (ANOVA) and correlation (Spearman's rank) between the affected activities. The *p*-value of ANOVA comes out to be 0.92 and that of Spearman's rank correlation to be 0.23. This shows that though there is a weak correlation between the perceptions of two stakeholders, the difference, is statistically non-significant. As shown in Table 4 under case study one, the ‘Δ’, which represents the difference between the number of affected activities in a case study, reflects minor differences in the perception of a particular risk between two stakeholders, with only one major deviation observed with $\Delta = 30$, due to the disparity of role or contractual obligations.

The risk of *design errors* presents a very interesting case; qualitatively it is a relatively low risk with scores 4.61 and 3 by client/PM and contractor respectively. However, it affects a large number of activities, with $\Delta > 20$. During the interview with project stakeholders, they reported the presence of a large number of errors in the design which negatively influenced the project.

A client representative discussed that “*there were many design errors but the contractor was competent enough to find and report them. As a result, we got back to the designer for correction. But on 14 activities, we suffered significant delays*”.

Whereas the contractor's representatives marked this issue in 44 activities and reported that “*the designer has made a lot of errors and some design elements were either missing altogether or not properly placed. We are still working on tender drawings because the detailed drawings are not provided. MEP, HVAC and IT network lines are intersecting with each other. We prepared the shop drawings and got them approved by the consultant to avoid delays. However, for major design correction, we consult with the designer through the client. This is one of the major issues for which we have suffered many delays and overwork, resulting in slow productivity*”.

The second case study consists of 84 major activities on which 32 shortlisted risks were assessed. For this case study too, two RBMs were developed based on the response from client and contractor. On application of statistical tests, the ANOVA *p*-value comes out to be 0.99, showing a non-significant difference between the responses from the two parties on the effect of risk on project activities. However, some major deviations were observed in a total of 4 risks with $\Delta > 20$.

The risk of project funding, with $\Delta = 30$, is considered broadly crucial for the client due to his obligations, but the contractor is not necessarily so concerned about it due to a better financial management by the client subsidiary. The interviewee from client reported that “*this project, despite being prestigious and flagship in nature, has faced funding issues. Since we did not want any delays, as soon variations were made, the issue of mutual consent on rates was raised between sponsoring agency and the contractor. The agency stopped the funding until the rates were approved by the board of directors and all standard procedures were completed. We made efforts and managed the contractor in a way that the project does not suffer and contractor can perform its duties conveniently*”.

The risk of slow response by consultant engineer to contractors inquiries, with $\Delta = 57$, was assessed as mildly significant only by the contractor due to the difference of role, with low probability. The contractor raised the issue of slow response and complained about timely feedback to help in critical decision-making. The risk of *conflict between the actual and contract quantities* due to VOs, with the difference in affected activities $\Delta > 20$, presents an interesting scenario. The client has marked this risk on more activities than the contractor who considered 15% variations as normal.

After assessing the difference between the opinion of client and contractor on a number of affected activities, it is imperative to discuss risks that have a high significance score. Either party assessed the risk of *variations by the client/change orders/rework* as the most crucial with a score of 16. It affects a total of 37 activities which are financially and managerially critical. The contractor reported that “*variations turned out to be the worst risk affecting overall project*”.

Further, the client and consultant considered variations not only as an isolated barrier to successful project completion but also as a major trigger for other risks. After the application of traditional risk

Table 4
Assessed traditional risks using RBM.

Assessed traditional risk/RBM	Case study # 01					Case study # 02				
	Client/PM assessment		Contractor assessment		Δ	Client/PM assessment		Contractor assessment		Δ
	Avg. score	Affected activities	Avg. score	Affected activities		Avg. score	Affected activities	Avg. score	Affected activities	
Variations by the client/change orders/rework	8.2	15	9.8	15	0	20	37	16.1	37	0
Payment delays	0	0	0	0	0	0	0	0	0	0
Project funding problems	0	0	0	0	0	19	30	0	0	30
Major disputes and negotiations	0	0	0	0	0	17	34	17.2	30	4
Slow decision-making	5.8	11	5.75	8	3	20	26	17.69	26	0
Contract breach by client/contractor	0	0	0	0	0	20	26	18	20	6
Lack of coordination between project stakeholders	0	0	0	0	0	17.1	34	17.17	34	0
Delay in contractor's claims settlements	0	0	0	0	0	18.9	30	19.46	30	0
Unrealistic program scheduling	0	0	0	0	0	11.68	50	15.06	30	20
Slow response: consultant regarding testing	0	0	0	0	0	0	0	0	0	0
Contractor financial failure	0	0	0	0	0	0	0	0	0	0
Inadequate risk management plan	3	47	2	44	3	2	84	2	84	0
Slow response: consultant engineer to contractor	0	0	0	0	0	0	0	6	57	57
Mistakes and delays in producing design documents	4	9	4	6	3	8.56	82	8.56	82	0
Major material procurement by client/contractor	16	2	20	4	2	0	0	25	4	4
Excessive approval procedures in administrative/government departments	12	2	0	0	2	20	2	0	0	2
Conflict between actual quantities and contract quantities	0	0	0	2	2	8.27	79	16	18	61
Corruption	0	0	0	0	0	11.04	84	11.12	82	2
Material changes and specifications during construction	2.28	7	2.1	7	0	20	37	20	19	18
Incomplete or inaccurate cost estimate	2	2	0	0	2	20	3	0	0	3
Inadequate or insufficient site information	6	1	6	1	0	10	1	25	1	0
Mistakes and discrepancies in contract document	0	0	0	0	0	12.36	22	0	0	22
Frequent change of subcontractors	3.7	10	3.12	9	1	0	0	0	0	0
Tight project schedule	0	0	0	0	0	4	81	7.95	81	0
Cost overrun	5.3	3	5.09	12	9	16.05	37	20	20	17
Poor quality of construction	0	0	0	0	0	6	76	6	76	0
Unpredicted technical problems in construction	2.4	5	6	1	4	20	1	20	1	0
Design errors	4.61	14	3	44	30	20	3	20	3	0
Lack of experience of contractor	0	0	0	0	0	0	0	0	0	0
Site access delays	0	0	0	0	0	0	0	0	0	0
Inappropriate construction methods	0	0	0	0	0	0	0	0	0	0
Preparation and approval of shop drawings	5.42	7	5	8	1	0	0	0	0	0

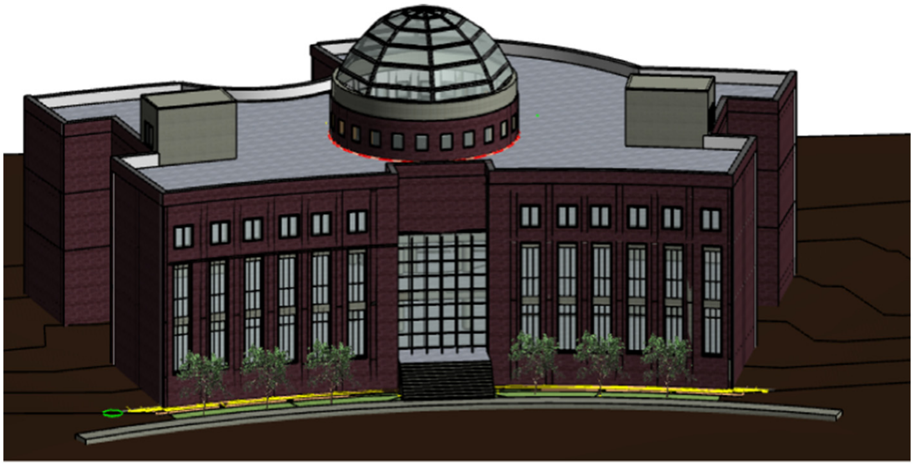


Fig. 4. BIM model of "*Central Information Resource Centre*".

management and developing pre-BIM risk registers, and further checking the influence and effect of risk tradeoff due to BIM implementation, BIM models of both case studies were developed as shown in Figs. 4 and 5.

Using these models, many risks were investigated, one of which is a risk of *design errors*. As shown in Table 5, when the BIM model was initially developed using tender drawings, it was noted that the stairs on the ground floor are not directly resting on the plinth beam but at a certain distance. This was brought to the attention of client and contractor. The contractor realized that this is a major design error which may result in a structural failure. Hence, a beam was approved and redesigned by the design consultant just under the stairs to support its

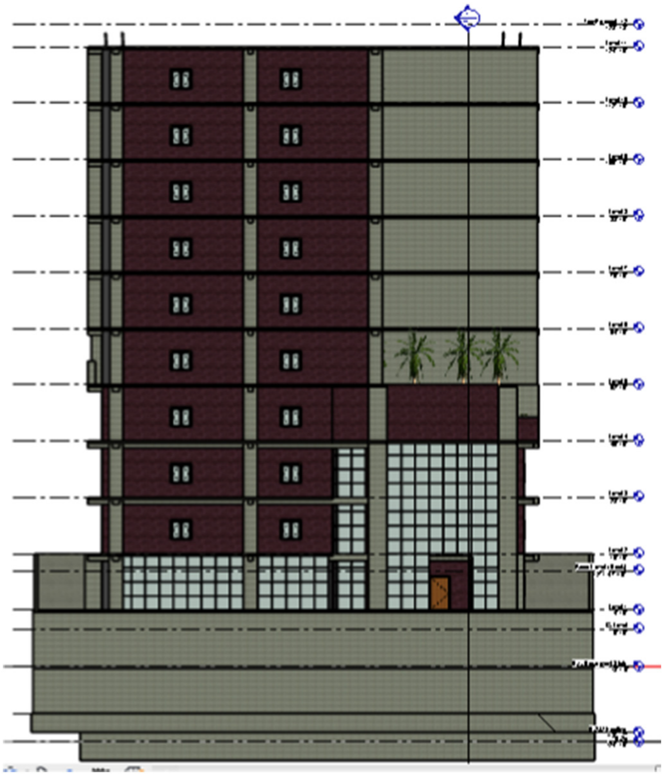


Fig. 5. BIM model of "*Multistory Commercial Building*".

load. But since this was not in the original design and the adjacent wall was an RCC retaining structure, the contractor had to drill the wall to construct a harness for joining the new steel with the constructed retaining wall as clearly seen under actual condition (see Table 5). Had BIM been implemented on this project since the beginning, the risk of design errors could have been effectively managed due to relevant technical features [17,18].

The same was observed in the second case study, as shown in Table 6, where a beam was originally designed on the center line of a grid (*E*-F) but due to a design error, drifted away on another grid (F-G), causing a loading complexity of extra moments. The design error was observed during model development and reported to the client. The designer shifted the beam to respond to this risk before its execution. Due to its features of clash detection and auto-generated warnings, BIM saved the project in terms of not only design errors and redo of works but also improved the quality and productivity.

These models were then simulated and analyzed in Autodesk Navisworks® and > 10 major and minor clashes were detected and removed in case study one. Similarly, model two, which was a bit complex due to two basements and eleven-floor levels, and variations in the design of HVAC, was analyzed for clashes. Though the designer reproduced the drawings due to change of HVAC loads and supplies from natural gas to electricity, it resulted in improper alignments and many clashes. During the development of BIM model, all these clashes were identified and reported to the client and designer to take early measures. BIM, once again, proved beneficial not only in studying the risk tradeoff but in eliminating major risks. It is imperative to mention that though the case studies of running projects pose more challenges in terms of data collection and model development, they present better opportunities to observe the effects of systematic interventions in action [114].

Subsequently, post-BIM risk register was developed for the high rated risks from the second phase and for their possible mitigation strategies, a total of 4 field and academic professionals from different countries were interviewed as shown in Table 7.

During the interview, an interviewee added that "*the risks in BIM are huge - there are very few projects that are contracted to detailed requirements needed to ensure that project participants understand exactly what they are required to do - contracting for BIM needs to be fixed first*".

All these research steps helped in understanding and appreciating the transformation of risk between pre- and post-BIM implementation. Qualitative and metamorphosis analyses were performed on the risks identified during first and second phases to find out the transformational shift in type, nature and potential of risk before and after employing BIM. The evolution was observed in the form of both elimination and transmutation of existing risks, and creation of newer ones. The evolution is studied in terms of causal chains where individual risk factors feed into main risk actors which are usually at the borderline between pre- and post-BIM cases. These actors carry forward the effect of interlinked factors into the next phases with or without transformation.

For a better understanding, the evolution is divided into three subgroups as *interlinked and transformational with affect*, *interlinked with no effect*, and *interlinked with elimination*. The first group is characterized by risks which transform after BIM implementation both in terms of their nature and significance. As shown in Fig. 6, slow decision-making is due to the lack of coordination and project management assistance, and quality of supervision, which is transformed in a post-BIM scenario with effects such as lack of clarity of business values, openness, trust and managerial commitment. Not only are these factors direct effects but they further transform into risk, influencing the project success.

Similarly, another transformation where risk is interlinked and evolved into the post-BIM world is shown in Fig. 7 where individual risk factor and main actor are equally contributing into their transformed counterpart.

Apart from the selected graphically presented evolution, many other factors have been observed to individually transform and influence the nature and significance of related post-BIM risks. For example, lack of coordination between project participants can give rise to B. Risk 6 and B. Risk 22. Also, major disputes are increased in effect in the post-BIM

Table 5
Identification of design errors (Case study - 01).

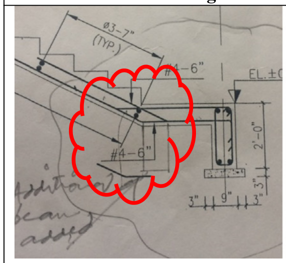
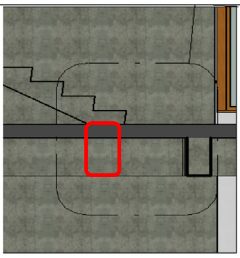
Case Study #01		
Tender drawing	**BIM model**	**Actual condition on site**
		

Table 6
Identification of design errors (Case study - 02).

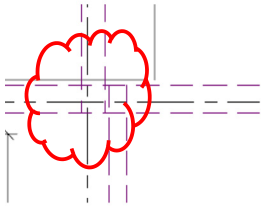
Case Study #02		
Tender drawing	**BIM model**	**After removal of error**
		

Table 7
Post-BIM based risk register.

Risk	Description	Value	Category	Proposed mitigation strategies
B. Risk 1	Lack of BIM knowledge	20	Organization	● Conducting webinars and seminars. ● Providing automated solutions. ● Introducing BIM courses and integrating with existing construction courses.
B. Risk 2	Lack of standard contract agreements	16	Project	● The client, with the help of BIM managers, should modify the basic contractual provisions to cater for the new project deliverables. ● BIM should be implemented under clear contract clauses by outlining the issues of copyright and liability.
B. Risk 3	Inadequate project experience	12	Organization	● By having clear project objectives and requirements. ● The request for proposal (RFP) process should solicit examples of previous projects. Not just a list but the detailed return on investment (ROI) of case studies should be presented. ● Hiring experienced BIM professionals. ● Performing pilot projects and small-scale adoption initially.
B. Risk 4	Unclear business values	12	Organization	● Requesting a business's mission statement and asking people in the company if they know what their mission statement says. ● Conducting project feasibilities to assess the impact of technology on profit.
B. Risk 5	Management process (change difficulties) - lack of understanding from 2D to 3D systems	12	Organization	● Initially launching the process in a controlled environment. ● Hiring BIM professionals. ● Selecting a 3D-First organization that has precedence for such implementation.
B. Risk 6	Reluctance to share open information	12	Organization	● Applying the concept of “big room” which helps with openness and better team coordination. ● Providing a controlled implementation initially.
B. Risk 7	Lack of integration of traditional 2D workflows with 3D tools - transition difficulties	12	Organization	● Defining clear workflows. ● Conducting a pilot project initially ● Utilizing experience of 3D-First teams.
B. Risk 8	Technical personnel - lack of familiarity with BIM	12	Project	● Choosing the right team and providing necessary training. ● Reforming existing teams by bringing in BIM professionals.
B. Risk 9	Considerable amount of time required to become familiar with software operation	12	Organization	● Either hiring BIM professionals or providing extensive training keeping in view that such skills demand a considerable amount of time.
B. Risk10	Rise in initial short-term costs (finances) - training, design reviews, hardware and software acquisition	12	Organization	● It is necessary to decide who will bear the upfront innovation costs. But, in addition, there must be an ROI plan to show the real beneficiary.
B. Risk11	No clear dispute-settlement mechanisms	12	Project	● By adequate BIM contracting - a clear LOD plan is essential to communicate the requirements. ● Devising comprehensive contract clauses.
B. Risk12	Risk of responsibility of entering correct data - making up-to-date model	12	Project	● There must be an end user pulling the mandate for the model to be up-to-date - if there is nobody checking and using the updated model, it is unlikely that the original development team will have any reason to keep it updated. ● Once the standards are set up, there will be fewer errors in populating the BIM model. ● Inducting clear contract clauses regarding liability before implementation.

case due to B. Risks 2, 11 and 30. Similarly, lack of experience of client gives rise to B. Risks 4 and 14.

The observed second transformation group is *interlinked with no effect*, which is characterized by the lack of transformation and effects. Here the background actors are joined to form a risk but its existence does not affect the induction of BIM. These risks lie outside the domain of BIM and will remain the same regardless of its implementation. One such example is shown in Fig. 8 where material logistics and supply chain related risks are shown to exist before and after the implementation of BIM. Though most risks will remain same in post-BIM case, few like slow delivery of materials, delay in special manufactured material and damage of materials in storage can be eliminated. Such an elimination contributes to the major risk of material availability through effective procurement planning of with the help of BIM [70].

In the third group, the background actors are interlinked and, ultimately, are permanently eliminated in the post-BIM world. This group provides the core of value addition in risk management due to BIM which not only justifies the investment for current project advantages, but also for overall industry development due to BIM-driven risk automation. One such example is shown in Fig. 9 where the main risk factor of poor quality of construction supported by background factors of unrealistic program scheduling/delays in completion [83], imperfect data transmission, lack of attention to contract documents [115] and HSE matters [116] are ultimately eliminated with implementation of

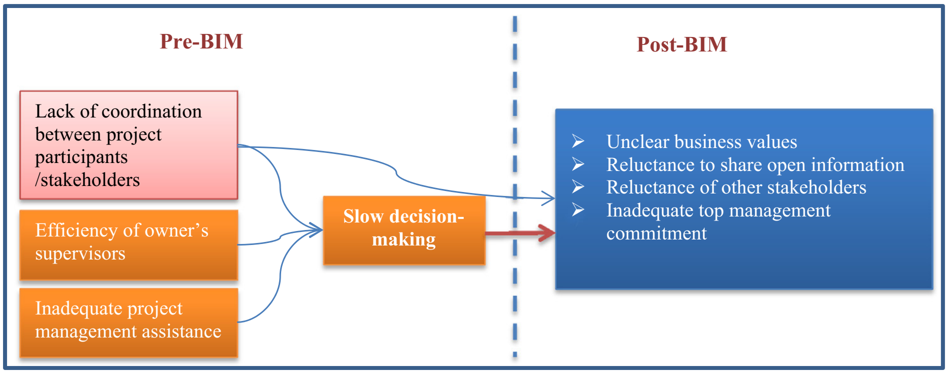


Fig. 6. Interlinked and transformational risks – Case 1.

BIM [13,16–19].

5. Discussion

Based on the collected data, the traditional approach to risk management was studied. The risks of VOs, reworks, payments delays, project funding issues, slow decision-making and disputes were shortlisted on the basis of their higher cumulative values. Various interlinking and triggering effects of risks along with their interdependencies were observed [1,84,95]. In the next phase, the BIM-induced risks were assessed under PI-values and high rated risks were further studied supporting the literature. Again the interdependency effect is observed [13,29,30,82].

After the application of traditional risk management and modeled case projects, a major transformation is observed due to BIM. The focus is not only towards elimination of risk but factors are also studied which evolve to become more or less significant after the implementation of BIM in construction projects. A causal evolution of substantial nature was observed during the evolution of risks from pre- to post-BIM scenarios. Considering post-BIM, some risks are completely eliminated, most of which were assessed as highly significant like variations by client, rework, design errors and constructability issues. On the other hand, some risks are newly developed based on the technological, legal, human resource, organizational, managerial and financial novelty induced after the implementation of BIM. Furthermore, several risks remain active with modification in their nature and score. Fig. 10 puts into perspective the entire length and breadth of investigated evolution in project risk due to BIM. It is imperative to observe that though there is a transformational relation between project risk in pre- and post-BIM scenarios, as explained in Figs. 6 to 9, a direct relationship between project and BIM risks is not empirically supported.

The innovative and automated integration of BIM with traditional risk management practices brings opportunities for the construction sector in terms of mitigating the highest ranked risks as established by the case studies. It provides a rare opportunity to bring a major shift in the overall project risk management philosophy. Risks evolve in terms of their nature, impacts and overall significance after a construction project is exposed to the modern technology of BIM. Other than its risk mitigation capability, BIM plays an important part in the stakeholder communication and collaboration, and improves the construction management practices. The overall integration process of traditional construction management with BIM makes it more systematized and offers an all-encompassing project management service.

It is extraordinary that a technology like BIM promising certain value has additional offerings as well. This helps in justifying the initial as well as continued investments on BIM for those construction organizations which are already adopting this technology. Other organization sitting on the fence can get tremendous motivation from direct and indirect value addition by BIM [117].

5.1. Future research guidelines

BIM has proven its benefits for construction industry by improving the project management practices. The current research has met its objectives based on the recent literature on risk management and BIM [13,19]. Also, another recent study has suggested addressing the current theoretical gap in integrating knowledge and experience into BIM for managing project risks [45].

Though not directly, the integration issue has been addressed through the methodology and findings of this research. Thus, an evolution in the understanding of the research problem and its objectives is observed. Taking benefit from this evolution, it is found that there is a lack of complete automation under BIM and project management. This paper does not only point to this limitation but also attempts to address

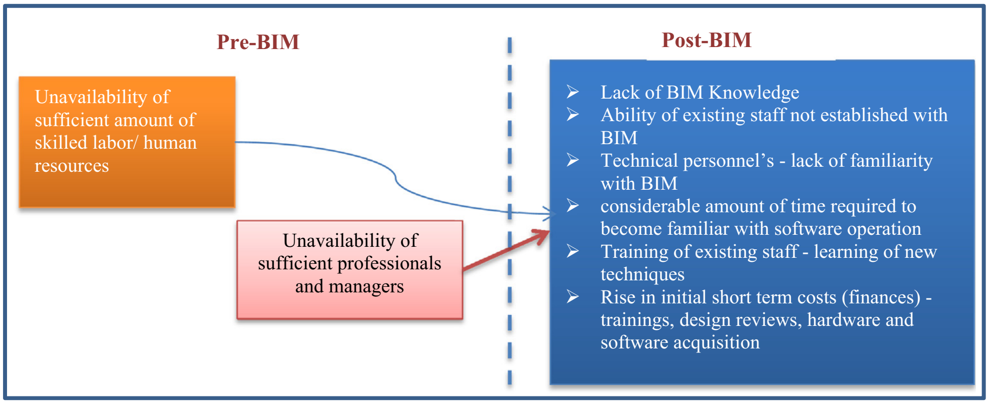


Fig. 7. Interlinked and transformational risks – Case 2.

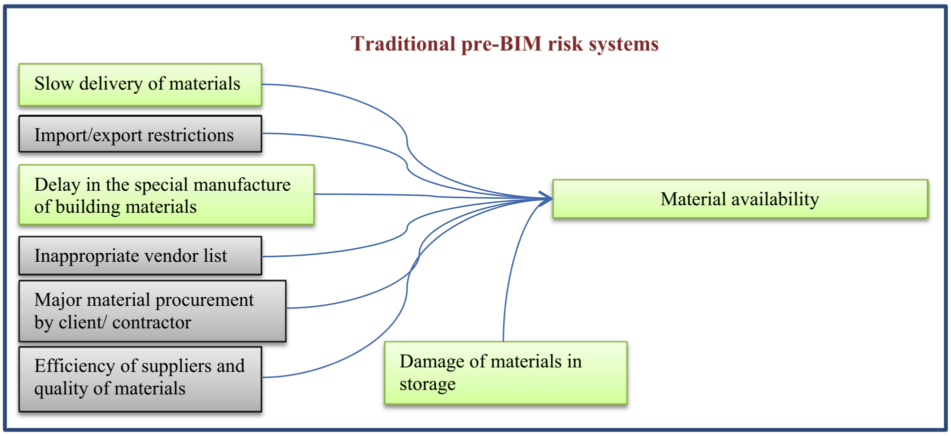


Fig. 8. Interlinked risks with no effect.

it by proposing a theoretical model and corresponding architecture of a BIM-integrated and fully automated project management plugin shown in Fig. 11. The proposed plugin offers risk contingency options to be used as management strategies for successful project completion.

The framework for the proposed plugin is such that BIM acts a central data repository and decision support system. Various BIM software tools can be utilized since the proposed design is theoretical, scalable and open. The suggested transaction model, whose architecture is presented in Fig. 12, is simple and uses architectural, structural, MEP, HVAC and electrical designs rendered into a BIM model along with other dimensions (n-D). Based on the processes and parameters mentioned in Table 8, the functioning of the proposed plugin initiates in the integrated cloud environment which will be assessed and contributed by the relevant stakeholders, as well as technical field experts.

The plugin uses all available details (n-D) as an input and proceeds further by involving relevant stakeholders. Based on the findings of the case studies regarding different treatment of risk by different stakeholders due to their perception or contractual responsibilities, the plugin attempts to serve the personalized information necessary for individual stakeholders to support decision-making.

The plugin then mines its risk database, which constitutes of published literature, reports and articles, and organizational knowledge of risk inventories from previous projects, to offer a detailed taxonomy of risk. The risk database acts as a menu card which practitioners can use to deliberate the appropriate risk exposure of their projects. The frequent up gradation of this repository will help users perform effective risk identification.

Based on the work schedule obtained through the activity tree and taxonomy items, an RBM is developed by requesting the corresponding P-I values. Cost inventory, as a 5D simulation [118], provides activity level breakdown of project cost which can be used for assessing risk impact. The business logic of the proposed plugin uses quantitative analysis tools, such as expected monetary value, to assess and estimate response strategies. In this particular case, all the probability-adjusted cost factors can be accumulated to provide the overall cost impact of project risks. This combined cost, in risk management terms, is called cost contingency [56]. As an output, the plugin will produce risk register along with activity-wise contingency cost in formats that are both industry standards as well as extendable for customized presentation.

The risk plugin, in its initial version, helps develop RBM, analyzes the individual risks and proposes a contingency budget to be included in the bid price. Though it is currently limited to offering only the contingent risk response in the form of cost, the continuous improvement aims at expanding the business logic by incorporating the necessary information from BIM pool, such as 4D for time buffer simulation to incorporate schedule contingency [119,120]. The enhanced data will call for other quantitative analysis techniques, such as decision tree diagram, fault tree analysis, probability distribution, sensitivity analysis to name a few, to be included in the plugin functioning [56].

Another limitation of the plugin is manual risk selection and opinion-based deterministic probability input. This limitation can be improved in the advanced versions by incorporating machine learning to suggest an inventory of relevant risks from a massive risk database [121], appropriate risk analysis techniques, and a suitable output form based on the stakeholder type and preferences. Due to its digital form, the proposed plugin can also benefit from the cyclic nature of risk management to perform regular analysis for dynamic updating of risk registers including newly identified risks, modified PI scores, and upgraded contingent and mitigating options. Such features will not only help eliminate the manual risk assessment needs, which reduce overall

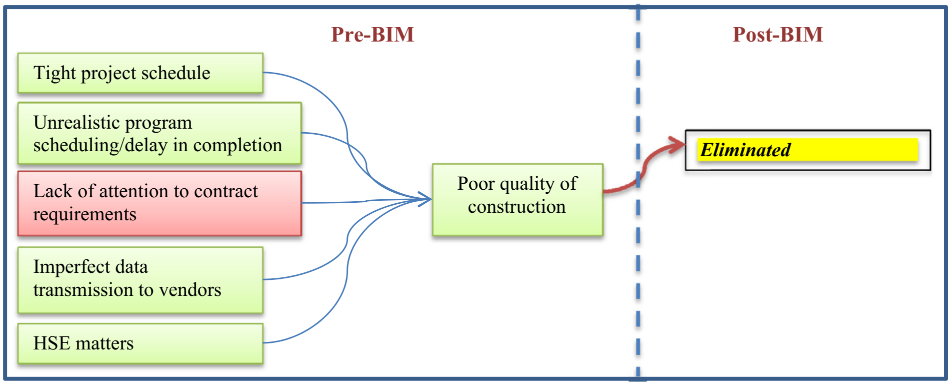


Fig. 9. Interlinked and eliminated risks.

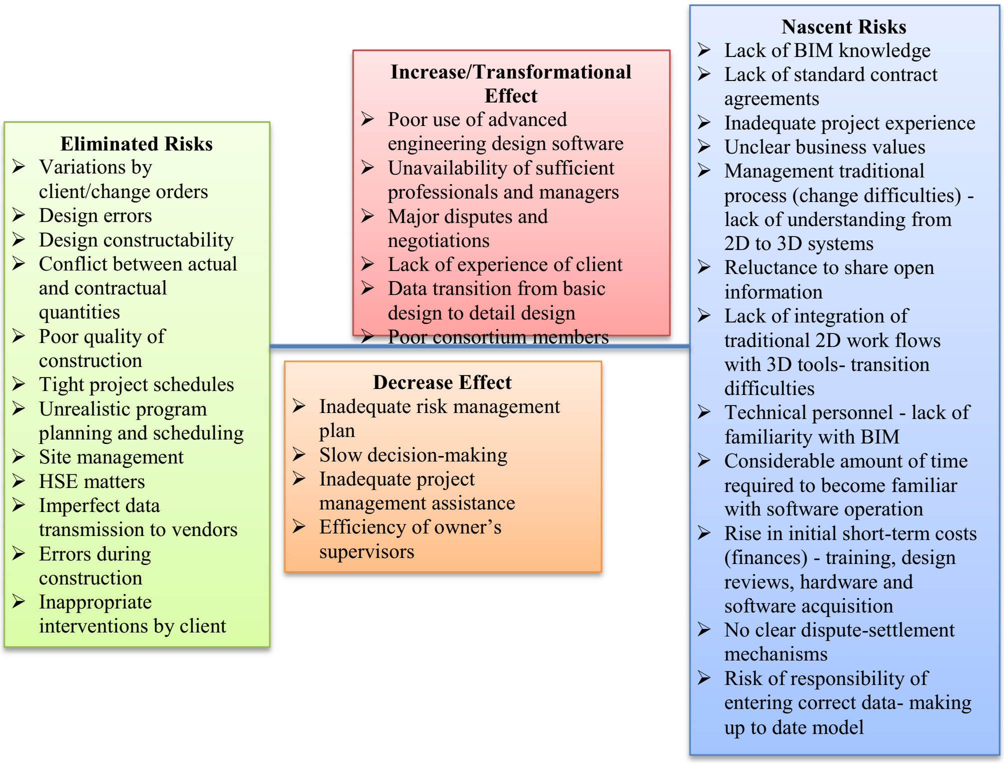


Fig. 10. Evolution of risks.

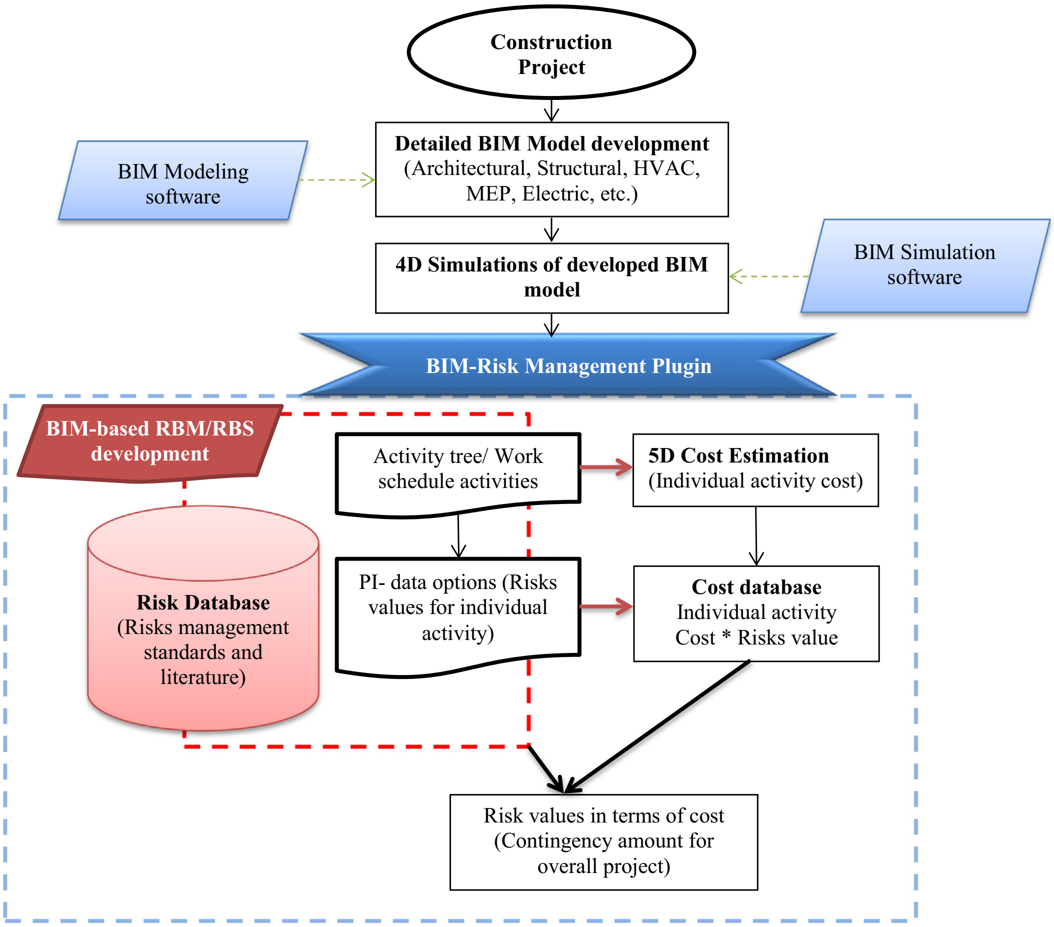


Fig. 11. Proposed BIM integrated risk management framework.

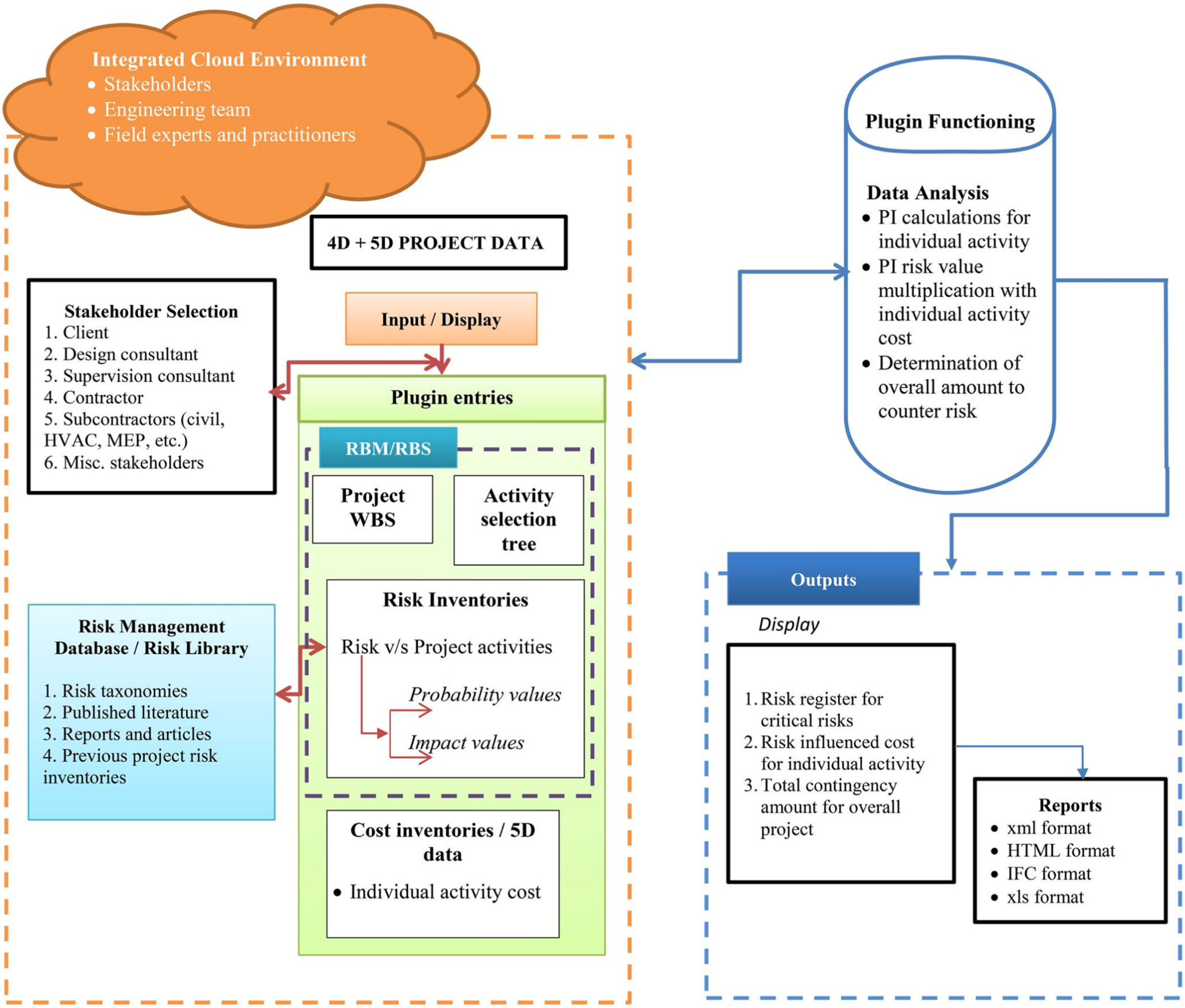


Fig. 12. Plugin architecture.

productivity but also highlight black swan events, greatly enhancing its efficiency [122].

The motivation behind proposing a dedicated plugin for performing management tasks is based on recent studies by Chen and Nguyen [123], who developed a Revit LEED plugin for directly and internally integrating web map service with BIM; Ahmad and Thaheem, who designed a specialized plugin to integrate social [124] and economic [125] sustainability concepts of building projects into BIM and Wang et al. [72], who use BIM objects to integrate schedule and cost information to establish an S-curve for project monitoring. The proposed plugin will systematize the risk aspect of building projects to achieve a seamless automated project management with BIM at the core of it.

6. Conclusion

Modern tools and technologies add value to management aspect of construction projects. The use of information systems and ICT has tremendously facilitated the practitioners in achieving greater project benefits and higher organizational productivity. BIM, which causes a paradigm shift in the modern construction industry, offers many direct and indirect benefits. The influence of BIM on risk management is studied in this paper. A systematic methodology, partly based on action

Table 8
Plugin processes and parameters.

Risk process	Corresponding plugin component/function	Parameter
Risk management planning	Integrated cloud environment	Stakeholders, experts; 4D/5D data
Risk identification	Risk database	Individual risk items
Risk analysis	RBS/RBM	Project WBS; Activity selection tree; Probability and impact values;
Risk response development	Risk register	RBM; Time, cost and other project details
Monitoring and control	Dynamic risk updating	Risk register; Updated inventories of risk, cost, time and other project details

research, is followed to observe the evolution of risk before and after applying BIM through case studies. To gauge the effectiveness of BIM in risk management, traditional risk analysis is performed on the case study projects. Using expert opinion of international construction practitioners, significant risks are assessed which seem to experience a transformation of varying degree after BIM implementation.

It is observed that most of the highest ranked risks are either entirely eliminated or significantly addressed, reducing their impacts considerably. Many existing risks experience a change in their overall ranking, and some new ones are born due to technological, legal and contractual innovation. The monetization of newly introduced risks is critical to gauge the risk tradeoff and justify investing in BIM. This cost quantification is beyond the scope of this work and is recommended for future studies. Despite that, detailed management strategies are proposed for the newly appeared risks using expert opinion. Based on the recommended future cost quantification of BIM induced risks, the strategies can also be refined.

To take the findings of this research towards a more automated project management scenario, a framework for BIM plugin is proposed which integrates project risk into BIM and proposes contingent risk response mechanism based on a systematic analysis. The proposed plugin will greatly facilitate the automated project management practices in the construction industry and help achieve project success parameters more efficiently. Though the current study is limited to a theoretical framework of the plugin, whose development is beyond the expertise of the authors, BIM software developers are recommended to take the lead by coding the proposed framework to help construction industry appreciate BIM benefits even more. This will result in a deeper and wider penetration of this promising technology into the construction sector.

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