ACADEMIA ENGINEERING

Review Article
Published: 2024-11-15
https://doi.org/10.20935/AcadEng7392

Framework to assess connection of risk factors and management strategies in Building Information Modeling

Amira Elnokaly[1], Ibrahim Dogonyaro[1,*]

Academic Editors: Kofi Agyekum, Angeles Blanco

Abstract

The implementation of Building Information Modeling (BIM) technology is advancing within the construction industry. However, there are several risks and challenges associated with the implementation process. Nowadays, there is a lack of research on management strategies to minimize or eradicate these risk factors. The objective of this work is to assess and select the most appropriate theoretical framework to examine the interrelations between risk factors and management strategies based on the publications available in Scopus and Google Scholar. Information has been processed using NVivo 12 Pro software via thematic and content analysis to extract risk factors and suitable theories/theoretical lens. The analysis reveals that the DeLone and McLean information systems (IS) success model is appropriate to examine risk factors within technical aspects from a single-dimensional perspective, while the Socio-technical system theory is preferred for considering socio-technical aspects from a multidimensional perspective. Thus, the new approach merges two concepts, namely, BIM-based construction networks and Leavitt socio-technical model, to analyze the situation in a more holistic manner. This article explores the theoretical concepts of risks in the BIM implementation and various methodological approaches from previous BIM and other information technology (IT)-related studies. The findings provide evidence from a single-dimensional perspective extending to areas with limited research such as the amalgamated aspects. Therefore, they establish a robust and adaptable theoretical framework with global relevance contributing to the generation of new knowledge. Further research is recommended to assess the financial and contractual theories for verification in BIM studies.

Keywords: *BIM, conceptual framework, management strategies, risk factors, theories, theoretical framework*

Citation: Elnokaly A, Dogonyaro I, Ahmed W. Framework to assess connection of risk factors and management strategies in Building Information Modeling. *Academia Engineering* 2024;1. https://doi.org/10.20935/AcadEng7392

1. Introduction

The architecture, engineering, and construction (AEC) industry is highly fragmented with data-intensive projects. The Building Information Modeling (BIM) technology is widely seen as the tool to manage the diverse knowledge workforce. Even though numerous studies have highlighted the benefits of BIM in governing construction projects, there are several issues associated with its implementation process. Various scholars have identified and categorized risk factors in implementing BIM from technical, social, organizational, and legal perspectives [1–6]. For example, Witt and Kähkönen [7] adopted the experiential learning theory, the structuration theory, and the systems theory as the theoretical lenses to examine the concept of BIM as a learning environment for AEC educational purposes. Nguyen and Akhavian [8] evaluated the synergistic effect of integrated project delivery (IPD), lean construction principles, and BIM on project performance measures using a qualitative analysis through grounded theory. Al Hattab and Hamzeh [9] employed the social network theory and simulation to compare traditional and BIM/lean-based practices for design error management in projects. Other scholars adopted conceptual frameworks. For example, Zhao et al. [4] examined risk paths in BIM but used a questionnaire survey to examine the likelihood of occurrence (LO) and magnitude of impact (MI) of the risks associated with the BIM adoption in the AEC industry. Zou et al. [10] integrated the Risk Breakdown Structure (RBS) into 3D/4D BIM for risk information management for bridges. These scholars identified and categorized the risk factors, but failed to align them with mitigating strategies. To fully understand the interrelationship between these variables (i.e., risk factors and management strategies), a theory/theoretical lens or framework is needed to guide the study. Theories come from an assembly of various sources in each discipline [11]. Therefore, the aim of this study is to review previous BIM and other information technology (IT)-related studies, focusing on different theoretical concept to select the most appropriate theory/theoretical lens to examine each of the risk categories and their interrelations with management strategies. The objective is to develop a suitable theoretical framework to examine all spectrums. The results will lead to

[1]School of Design and Architecture, University of Lincoln, Brayford Pool, Lincoln LN6 7TS, UK.
*email: 18709117@students.lincoln.ac.uk; i_dogonyaro@yahoo.co.uk

hypotheses (quantitative) or propositions (qualitative) or limited generalizations that could assist researchers to investigate each aspect discretely. This article is organized as follows: The first section reports BIM studies, highlighting the risk factors in chronological order. Then, it reviews the theories/theoretical lens and theoretical frameworks in BIM and other IT-related studies. Section 2 discusses the research methodology, encompassing the approach and context, and reports on the paper retrieval process. It also provides details of the research design, the theory/theoretical lens selection strategy, risk identification and categorization, and the development and application of the theoretical framework (i.e., the blueprint) to examine the risk factors (BIM-RBS) and management strategies (BIM-RBS-MS) considering a broad range of spectrums (i.e., BIM, RBS, Management Strategies (MS)). Section 3 provides the analysis and discussion of the theoretical perspective, examines the results and contributions, and explores their practical implications. Section 4 presents the findings of the study and outlines the current challenges and limitations. Finally, the last section concludes the research study with recommendations.

1.1. Review of previous BIM studies in chronological order

BIM as a methodology is a digital project development integrated with various technologies. It enables various design options and improves collaboration, communication, virtual representation, and clash detection for risk management [12]. The implementation process evolved from the basic three-dimensional (3D) architectural model and integrated with other multidisciplinary components. This provides a virtual platform for various stakeholders to communicate and exchange relevant information throughout the design and implementation stages of the project. The various models popularly designated as "Dimensions" (Ds) evolved over the years from 1D to 10D. 1D BIM is the preliminary foundation for the documentation of all requirements associated with the construction project lifecycle. 2D BIM models a project in two dimensions, and it is limited to a simple X- and Y-axis representation of the project design and drawings. 3D BIM increases the clarity and rigor of the process by undertaking design and planning in a three-dimensional environment that entails integration and visualization of the graphical and non-graphical information [13]. The practical application of the 3D BIM began to evolve in 2003. Goldberg [14] highlighted the benefits of BIM application to designers in creating virtual aspects and solving program issues (i.e., scheduling 4D). 4D BIM involves the incorporation of schedule into the 3D model of a facility, which enables detecting errors in timing and the sequence of activities. By 2005, Sabo and Zahn began to identify legal issues while implementing the technology [15], which implies that legal issues have been a problem in implementing BIM from the start to till date. The next year, Baxter [16] raised the question: why the industry still forsakes profits? Goldberg [17] insisted that 4–5% of cost could be saved by utilizing the BIM for cost estimates (5D), as the software would minimize the risk of human error [17]. 5D BIM incorporates cost estimates into 4D BIM to enable integrated cost planning and project budgeting. However, there was no unified consensus on BIM evaluation based on its benefits to verify such savings at that time. In 2007, Ambrose began to question the roles and rules of traditional conventions, exploring how academia can prepare architectural students for digital practices, especially for BIM [18]. Afterward, further research was conducted by Roorda and Liu [19]. They started to identify more issues such as conflicts between disciplines due to geographic location of different stakeholders, lack of standards, and hardware/software limitations on computations. However, one of the identified benefits of using BIM is its ability to work across different geographic locations. In 2009, Azhar and Brown [20] investigated the viability of BIM-based sustainability analyses (6D) based on environmental concerns, but they failed to address the issues related to the implementation process. 6D BIM optimizes energy consumption, reduces the long-term costs associated with running the facility, and improves performance while significantly contributing to sustainability objectives [21]. Between 2009 and 2010, Sulankivi et al.'s [22] and Kamardeen's [23] research projects focused on utilizing the BIM technology for analyzing safety risks. As the BIM implementation has increased in recent years, Azhar [24] researched its current trends, benefits, possible risks, and future challenges in the AEC industry and provided future considerations. However, they only classified these risks into two categories: legal and technical aspects. Becerik-Gerber et al. [25] focused on the facilities management (FM) dimension (7D), examining how BIM can serve as a valuable platform to enhance FM practices. 7D BIM includes more lifecycle-related information for the operation and maintenance of the facility from design to demolition. In 2012, Hooper and Ekholm [26] explored a method for defining the content of model information deliverables to solve technological issues of integrated information management such as interoperability. The following year, Kivits and Furneaux [27] highlighted the advantages and barriers associated with BIM and identified issues such as intellectual property rights and liability risks, including contracts and the authenticity of users. This clearly indicates that legal issues were still a problem in 2013. Furthermore, Chien et al. [28] identified 13 risk factors in BIM adoption and classified them into six risk categories (i.e., technical, management, financial, legal, environmental, and political risks). They also proposed relative risk-response strategies. However, these risk-response strategies were limited only to the construction phase. The integration of BIM with other components increased over the years. Alizadehsalehi et al. [29] investigated the use of BIM integrated with laser scanning technologies and concluded that the limitations of BIM include the cultural resistance from people who fail to keep up with the new developments and prefer to use the old approach. By 2016, Zou et al. [30] addressed the current theoretical gap in integrating knowledge and experience into BIM for risk management, by establishing a link between RBS and BIM. The following year, Oraee et al. [31] investigated collaboration in BIM-based construction networks (BbCNs), which consisted of context, process, task, team, and actor as the theoretical lens created through integration of relevant frameworks. Further to the challenges of implementing BIM, Ganbat et al. [32] identified research trends and opportunities for risk management in international construction supported by BIM. They classified international construction risks into nine risk categories (i.e., political, social, legal, economic, technical, contract, management, partners, and environmental risks) based on three aspects: the risks initiated by BIM, the risks BIM cannot solve, and the risks it can resolve, while clearly distinguishing between internal and external risks. These internal and external factors help in distinguishing the scope of risks, whether they are within the organization's control or driven by external circumstances. However, the study was not an empirical study covering all the fragmented construction phases. In an attempt to improve the BIM technology, Lee et al. [33] focused on the superior visualization aspect of BIM for safety (8D). 8D BIM deals with the integration of onsite health and safety requirements to ensure the safety of all personnel during the different stages of construction and the operation of the facility. Then, Georgiadou [1] presented an overview of benefits and challenges of BIM adoption in UK residential projects. Their findings suggest that there are financial barriers in developing digital capabilities, particularly for small-medium enterprises (SMEs). This suggests that only larger companies who can invest in BIM can gain its benefits. Kassim and Ismail [34] identified lack of coordination (9D) as the main risk factor in using BIM for mechanical, electrical, and plumbing (MEP) engineering practice during the Covid-19 outbreak. 9D BIM is the integration of lean construction requirements that emphasizes the resource management techniques to improve coordinating the allocation and use of materials, labor, equipment, and tools during the facility lifespan. As the BIM technology advanced, 10D BIM identifies and eliminates obstacles to productivity throughout the design, construction, and delivery of a facility. The advantage of an industrialized construction is that it incorporates disaster management plans to improve productivity by encouraging the use of drones, manufacturing machines, and artificial intelligence to automate planning and control procedures of engineering [13]. Darkoa et al. [35] recommend incorporating the concept of Industry 4.0, representing the era of digitization in construction (i.e., Construction 4.0), to align project risks with BIM-based risk management strategies. However, Torrecilla-García et al. [36] argued that implementation of Industry 4.0 technologies in the construction industry as an all-inclusive system of management is still at its infancy. The integration of BIM advanced with Internet of Things (IoT) to constantly store and update data. Incorporation of automated and continuous management with reliable data-driven intelligent decision-making in construction can save time [37]. However, Liu et al. [38] argued that IoT and BIM lack the function of data mining and analysis, but combining Digital Twin with BIM can improve the efficiency of safety management in the construction industry [36, 38]. Pan and Zhang [37] recommended a digital twin platform with built-in BIM event log mining functions that will enable project managers to create efficient construction plans on time and save cost on material deliveries. In 2022, Alavi et al. [39] and Fang and Yuan [40] identified interoperability issues in their BIM-based studies. Waqar et al. [41] identified five barriers to BIM adoption in small construction projects. In their study, Okika et al. [42] employed a systematic approach to identify and manage interface risks between project stakeholders. **Figure 1** shows BIM articles reviewed from 2000 to 2024 in chronological order.

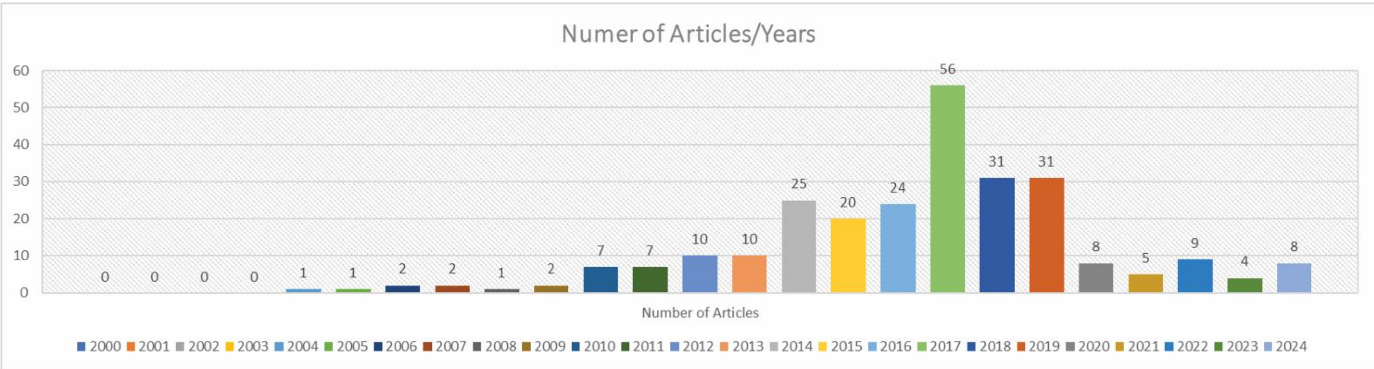

Figure 1 • 20 Years of Building Information Modeling journal articles in a chronological order.

1.2. Review of theories/theoretical lens and theoretical frameworks in complex information technology systems and BIM studies

Over the years, scholars have applied various conceptual frameworks to guide the implementation of complex IT systems such as BIM [43], while others have used theories/theoretical lens and theoretical framework to investigate and improve BIM implementation procedures. However, there is some confusion to what these concepts actually mean when applied in research. Kivunja's [44] study clearly distinguished between theory, theoretical framework, and conceptual framework, thus enabling an in-depth review of various theories/theoretical lens in BIM and other complex IT-related studies to evaluate their applicability in understanding risk factors and developing effective management strategies.

1.2.1. Theories

Theories are statements of causation that explain the relationship among variables, phenomena, and concepts [45]. These are both the source of new ideas and the basis to accumulate scientific knowledge [46]. The review presented in this article indicates that numerous BIM studies have been conducted using theories. For example, the activity theory refers to a theoretical approach for understanding human mental functioning and actions. It focuses on how history, culture, and social interactions shape individual awareness and the organization of collective activities. The organization of collective activities is referred to as the activity theory [47, 48]. As Levant [49] suggests, it is not only a theoretical approach, or a way of thinking, but also the means to organize human activities, because using old technology and new technologies (such as BIM) concurrently may lead to the emergence of contradictions [50]. Nevertheless, Levant [51] argued that the activity theory should not be regarded as a narrowly psychological theory but a broad approach with new perspectives. It develops novel conceptual tools for tackling many theoretical and methodological questions across the social sciences. Its triangular diagram made of six interrelated elements (i.e., subjects, tools, object, community, rules, and division of labor) allows multiple networks of descriptions and interpretations of a dynamic situation according to Zahedi et al. [48]. This suggests that it can be employed to examine six interrelated components in BIM studies. Zahedi et al. [48] utilize the activity theory for studying complex situations such as interdisciplinary collaboration in design projects. Nonetheless, it supports the argument in Poirier et al.'s [51] study that the impact of BIM on collaboration is detected through inconsistencies that arise within the activity system.

Researchers have applied theories, such as actor network theory (ANT), that support the understanding of the impact of BIM by rearranging or limiting project networks [51]. In their studies [51–54], researchers utilized ANT to examine and understand organizational changes, as its enables the analysis of both human (i.e., change of their roles and relationships in the actor network) and non-human elements influenced by the implementation of a new technology (e.g., BIM) [52]. ANT explains the interconnectivity of human and non-human elements (i.e., persuasion, resistance and compromise, invitation and exclusion of things, work linkages, and other networks) within actor networks [53]. For example, Lindblad [52] utilized ANT for gathering and analyzing empirical findings to describe how and to what extent technology influences human behavior. However, Rowland [54] argued that ANT does not explain why networks take on specific forms. Instead, it offers a new way of thinking about society, viewing it as interconnected with nature and technical artifacts rather than as a separate domain. Therefore, Rowland's [54] argument suggests that ANT challenges this traditional separation, proposing that society, nature, and technology are interconnected and should be understood as part of the same network, rather than distinct and independent from each other. This shows ANT's applicability to examine three components by implementing BIM, that is, the human (i.e., social aspects), non-human (i.e., technical aspects), and organizational changes (i.e., organizational aspects).

Numerous studies have been conducted using the socio-technical theory [43, 55–58], which emphasizes the importance of human experience within systems and its relationship to the overall performance of those systems [57]. This theory states that technology and people are interdependent in a work system (i.e., the technology affects people's behavior, while people's behavior affects the working of technology) [55, 56]. Sackey et al.'s [43] socio-technical system (STS) analysis focused on incorporating technology into work system, but based on their observation, they argued that implementing a successful technology, such as BIM, requires an understanding of the organizational context (i.e., an organization's structure and workforce). However, further argument by Miner [58] indicates that the socio-technical approach does not recognize the variation of social needs among project participants and does not address the internal dynamics that happens among the participants in a work group. Nevertheless, the theory is based on the principles of considering the social and technical systems concurrently when changes are implemented rather than emphasizing one over the other [56]. This suggests the theory's ability to examine two components implementing BIM, but the organizational aspect needs to be considered. According to Miner [58], from a socio-technical perspective, other theories, such as information processing theory, as a whole have not proved to be agreeable to meta-analysis, but qualify as unconscious in nature, given their stand on automatic processes and their closeness to other interpretations of implicit processes. This suggests that the information processing theory has limitations unless validated in BIM-enabled projects.

According to Williamson [59], the organization theory can be divided into micro and macro levels from an organizational perspective, and categorized into natural, rational, and open systems approaches. The significant aspects of this theory are as follows: it first describes human actors in more realistic terms; second, it provides the awareness of behavioral regularities; third, alternative modes of governance are different in distinct structural ways; fourth, much of its action resides in the micro analytics; and finally, it provides importance to cooperative adaptation. On the other hand, Organization Development Theories aim to explain changes within organizations by analyzing their ideas, values, and behaviors. These theories focus on understanding the complex relationship between organizations and the environments in which they operate [60]. However, their applicability to investigating BIM still requires validation. Alternative theories, such as organizational discontinuity theory (ODT), highlight how boundaries create communication and coordination challenges for project participants who must work across different boundaries to complete their tasks. For example, boundaries of place, such as the location of a company, can lead to increased miscommunication and conflict when working across geographic regions. Additionally, boundaries between different disciplines with distinct cultural differences, as noted by Crowston et al. [61], can further complicate collaboration. They argue that a boundary becomes an issue when an individual observes a change in information and communication flow that needs to be addressed in a project. This suggests that these theories are viable to examine two components by implementing BIM (i.e., social and organizational aspects). Nevertheless, Klein [55] employed the contingency theory to analyze the relationships between structural and behavioral factors to examine how an organization functions in its environment. The theory proposes that there is no single "best" way to organize an organization, as the optimal structure depends on various factors. Therefore, it is most effective to organize based on specific circumstances. AlKalbani et al. [62] focused on investigating socio-organizational factors within organizations and applied the technology-organization-environment (TOE) theory. They argued that the adoption and implementation of technological innovations in organizations are influenced not only by technological and organizational factors but also by the surrounding environmental contexts. This indicates that the technical and environmental factors should be considered while applying these theories to examine the organizational aspects of implementing BIM.

Furthermore, there are theories of change management such as "push" model which emphasizes a top-down, short-term approach focused on financial results, and the "grow" model which adopts a human resource perspective aimed at long-term development and enhances organizational capacity through the concept of learning organizations. These models acknowledge people's individual feelings, aspirations, and assumptions when engaging changes and emphasize developing new ways of thinking and working for organizational members, providing a way to understand the problems that may arise while implementing BIM [63]. Another change management theory for reactive and proactive processes is the constructivism theory (i.e., reactive processes are applied due to a change to minimize its impact, and proactive processes are pre-prepared to minimize disruptive effects of changes) [64]. These theories can be employed to examine the interrelations between two components involved in implementing BIM: the social and organizational aspects. Additionally, other theories, such as adaptive structuration theory (AST), can be used to analyze IT adoption situations in organizations, focusing on human actions during interactions with technology. Some scholars have expanded the theory from the duality of structure concept to include the duality of technology proposition, which proposes that technology is both created and modified by human actions while humans use the technology to achieve specific goals [7]. This clearly indicates that both social and technical components must be considered when utilizing the theory to investigate BIM.

The review of theories from a social perspective further highlights several viable frameworks that can be used to examine BIM implementation, such as the theory of reasoned action (TRA) and the theory of planned behavior (TPB). These are the initial behavioral models that explain how individuals shape their behavior, based on internal (individual attitudes) and external (normative beliefs) factors. It was extended to include developments in the variables and thus named the TPB [51, 65]. The mediated action theory focuses on the tensions that arise from individuals' histories of participation within a broader system of relationships. This theory can be used to examine important aspects of their sociocultural and historical contexts while remaining open to unexpected connections that may emerge during the analysis [47].

From a financial and economic perspective, Levine's [66] study indicated that institutions, markets, and financial instruments emerge to mitigate the effects of transaction and information costs based on theoretical models (i.e., theoretical frameworks). Traditional finance theory tends to focus on cross-sectional diversification of risk, which can inspire innovative activity. As the financial system may mitigate the risks associated with individual projects, firms, and industries, they can also accelerate a technological change such as the use of BIM to foster economic growth. Hence, the theory suggests that such systems influence growth by enabling information and transactions costs. This improvement enhances the acquisition of information related to firms: financial exchanges, risk management, resource mobilization, and corporate governance [66]. However, there are limited financial theories in the studies evaluating BIM that are reviewed in this article.

1.2.2. Theoretical framework

Theoretical framework is the "blueprint" of the research inquiry and serves as a guide [11]. It is the structure that summarizes concepts and theories, and it can hold or support them in a research study [44]. BIM is implemented in combination with IT in a social environment, and its success in organizations depends not only on technical issues but also on social issues [67]. Hence, to examine this integration requires a theoretical framework and a means of evaluation for an effective BIM implementation. Some studies [9, 37, 67] utilized the social network theory (SNT) and the associated social network analysis (SNA) to examine interactions among individuals engaged in construction projects. Maskil-Leitan and Reychav [67] employed SNA to investigate social risks in their study because it helps to visualize roles and relational patterns among project participants. In this context, Al Hattab and Hamzeh [9] argue that SNA examines not only the relationship structures among project participants but also the underlying dynamics within those relationships. The visual graphs used in mapping social networks consist of nodes that represent the components or actors being studied, illustrating the interconnected relationships between people and networks.

The review further indicates a theoretical framework known as the DeLone and McLean [68] information systems (IS) success model. It is an analytical tool for measuring complex dependent variables in IS research [68]. Dowsett and Harty [69] extended this model to assess the process of implementing BIM. The model evaluates several dimensions of success including technical success, semantic success (i.e., information quality), and effectiveness success (i.e., "system use" user satisfaction, and impacts on individuals and organizations) [68]. However, Dowsett and Harty [69] argue that while each of these dimensions is necessary, they are not sufficient on their own to guarantee the desired outcomes in their research. For example, if a system is not used, there will be no consequences or benefits. Conversely, if the system is used excessively inappropriately, it may also fail to provide any benefits. Thus, they employed six constructs of the model: System Quality, Information Quality, Service Quality, Intention to Use and Use, User Satisfaction, and Net Benefits. However, there are other infused measures such as market measures, economic measures, usage measures, perceptual measures, and productivity measures [68]. This clearly indicates the flexibility of the theoretical framework, with the possibility of extending the model to examine BIM.

There are other models that exist related to technology adoption theories such as technology diffusion theory, which states that the process of adopting technology starts with the awareness to integrate a technology to resolve an organization's specific problem [70]. Hong et al. [70] describe this model through reviewing the existing literature by characterizing each principal component (e.g., implementation challenges, knowledge support, operation risks). This suggests that BIM is beneficial in establishing a theoretical framework that involves reviewing the existing literature and theories to develop a suitable model.

The proposed theoretical framework to examine risk factors with possible links to appropriate strategies in BIM studies relating to all spectrums is associated with the extended version of the socio-technical theory, which is also known as the Leavitt socio-technical model developed by Leavitt [71]. Sackey et al. [43] utilized the model to examine BIM implementation process in an organization in relation to the socio-technical framework. Their findings suggest a complex and interrelated set of incidents, events, and gaps unfolded which threatened the structures of stable organization norms and work processes. Merschbrock et al. [72] similarly applied the model to investigate collaboration in BbCNs, because of the inclusion of new components (i.e., technology, actors, tasks, and structure, which are four components that act in synergy to achieve a balance in STSs rather than two). This suggests that the model can be extended to include more components for developing a framework that will be suitable to examine all aspects for implementing BIM.

1.2.3. Conceptual framework

The conceptual framework is the logical conceptualization of an entire research project. It comprises of the following:

- Identifying the research topic
- Problem to be investigated
- Questions asked
- Review of the literature
- Theories to be applied
- The methodology, including methods, procedures, and instruments

- Data analysis and interpretation of the findings
- Conclusions with recommendations [44].

The review from a contractual and legal perspective suggests that there is no descriptive theory that explains what the law is or a complete normative theory that explains what it should be with regard to contract laws that comprehend a broad domain [73], such as BIM implementation complexity consisting of various aspects. Therefore, a conceptual framework is the logical approach. As Schwartz and Scott [73] argue, without a theory of interpretation to understand the meaning of the content of parties' agreement and its legal implications, a court cannot enforce contracts. The conceptual framework concerning contractual and legal aspects should first encapsulate tort theory (i.e., a tort is a legal mistake, focusing on legal consequences such as accidents, and the relevant forms of liability that are strict liability and negligence). Circo [74] indicated that it appears to become a persistent force in allocating liability arising from shared-design practices, especially in BIM processes. Secondly, the theory of contractual relationship management that suggests managing relations with trust among parties produces the most effective relations between parties [75]. Thirdly, contract theory is the study of how people and organizations construct and develop legal agreements. However, Circo [74] further argues that a tort approach that involves commercial relationships tends to be inferior to a contract approach for allocating liability such as property damages and economic injuries, concluding that the industry is skillful at developing project delivery systems and contracting structures that will respond to a constantly changing environment. Therefore, it commercially allows participants to sensibly protect their own legitimate interests via risk management techniques and contract negotiations. This relates to Hartmann and Fischer's [74] argument that it is better to understand the processes behind the use of BIM rather than just the BIM technology itself. Contracts should be written in a standard form that encapsulates not only the use of BIM technology but also the roles and responsibilities of all parties, collaboration protocols, data sharing requirements, and mechanisms for resolving disputes related to the implementation of BIM to name a few. They suggest that writing contracts covering technological features in detail is not sensible, because technology such as BIM is changing rapidly to be covered through detailed legal agreements. Nevertheless, for understanding organizations and the success of large corporation, Butler [76] suggests the contractual theory, which provides the theoretical and empirical bases, including the appropriate role of privately negotiated contracts and mandatory legal rules. However, these theories need validation for investigating BIM.

The grounded theory [77] is a methodology that involves a conceptual framework without including a theory initially, by collecting and analyzing actual data through fieldwork to identify, develop, and integrate concepts. Aksenova et al. [78] adopted grounded theory to analyze data from interviews and literature to generate an explanatory and descriptive view of their study. Moreover, some scholars have acknowledged that grounded theory is a form of qualitative research for developing a theory [8, 77–79] that can be used in BIM studies.

In reviewing the literature, these scholars [8, 77–79] utilized different theories/theoretical lens to examine BIM implementation, while others develop their own theoretical framework as presented in **Table S1**, Supplementary materials, which also includes the risk factors extracted from these studies.

There are numerous research efforts to identify risk factors in implementing BIM, but the categorization of these risk factors is limited only to single-dimensional aspects and lacks appropriate strategies. This study will attempt to bridge this gap by developing a suitable theoretical framework to examine the interrelations between these variables extending the scope of the model (i.e., two-dimensional aspects).

2. Research methodology

To investigate risk factors in implementing BIM aligned with appropriate strategies, a theory/theoretical lens to examine the connection between risk factors and MS needs to be taken into consideration. The investigation described in this article included a chronological review approach to analyze BIM risk factors and develop BIM-RBS. An integrative review approach was adopted adhering to a systematic process to discover management strategies and establish BIM-RBS-MS. Therefore, an in-depth review approach on theoretical concepts will provide the theoretical framework to deeply examine the link between the two variables (i.e., BIM-RBS and BIM-RBS-MS). In-depth reviews are transparent and explicit about what was conducted in this study, which can be replicated and updated. They minimize the duplication of effort and reduce bias as conclusions are not overly influenced by the most accessible research [80].

2.1. Research approach, paper retrieval, and research design process

The philosophy on research reflects on how various authors believe in obtaining, analyzing, and interpreting data regarding the phenomenon under investigation. The two philosophical divisions are ontology and epistemology [81]. While ontology is the study of the nature of reality, including its categories and interrelations, this article is focused on the theory of knowledge, how the reality is perceived, and the method of evaluation, also known as epistemology, to investigate the ontology aspect. A theoretical lens guides a study, while a theory acts as a bridge between variables, explaining how and why they are related [45, 81]. Hence, the approach in this study considers numerous research processes with the growing nature of the phenomenon under investigation (i.e., theoretical concepts to examine BIM implementation risks aligned with strategies) [43]. Steps 1–6 of the research design in **Figure 2** show the process, scope, and the path taken for conducting this research.

Step 1: For retrieving papers, 317 relevant publications in English, such as academic journals and conference papers, were downloaded from online databases of Scopus and Google Scholar from 2000 to 2024. These databases are adequate because they cover a wider range of multidisciplinary scientific literature and contain more journals compared to other popular databases [31, 82]. For the search of publications, first three sets of keyword terms were used, namely "building information modeling," "risk," and "management" on the search engine, and the search strategy was triangulating these terms. Second, "risk management," "management strategies," and "BIM" or "Building Information Modeling" were used. Finally, the search incorporated the term "theories" to identify relevant theoretical frameworks and concepts associated with the use of BIM in risk management. Articles not retrieved in Scopus were retrieved by typing the keywords on Google Scholar. The analysis found 94 articles relevant for identifying risk factors, 30 articles relevant to risk management associated with BIM implementation management strategies, and 35 articles related to various theories/theoretical lens, making a total of 158 articles. The full text of each article was read and carefully screened to check its content, theoretical perspective, and methodology.

Step 2: These articles were saved in a reference management program (RefWorks), enabling the convenient elimination of duplicates [31, 32, 82]. NVivo 12 Pro software was employed for coding and analysis similar to Aksenova et al. [78]. This study focused on an innovative method by connecting various theoretical concepts to establish a framework suitable to examine the interrelations between risk factors and management strategies (i.e., BIM-RBS and BIM-RBS-MS).

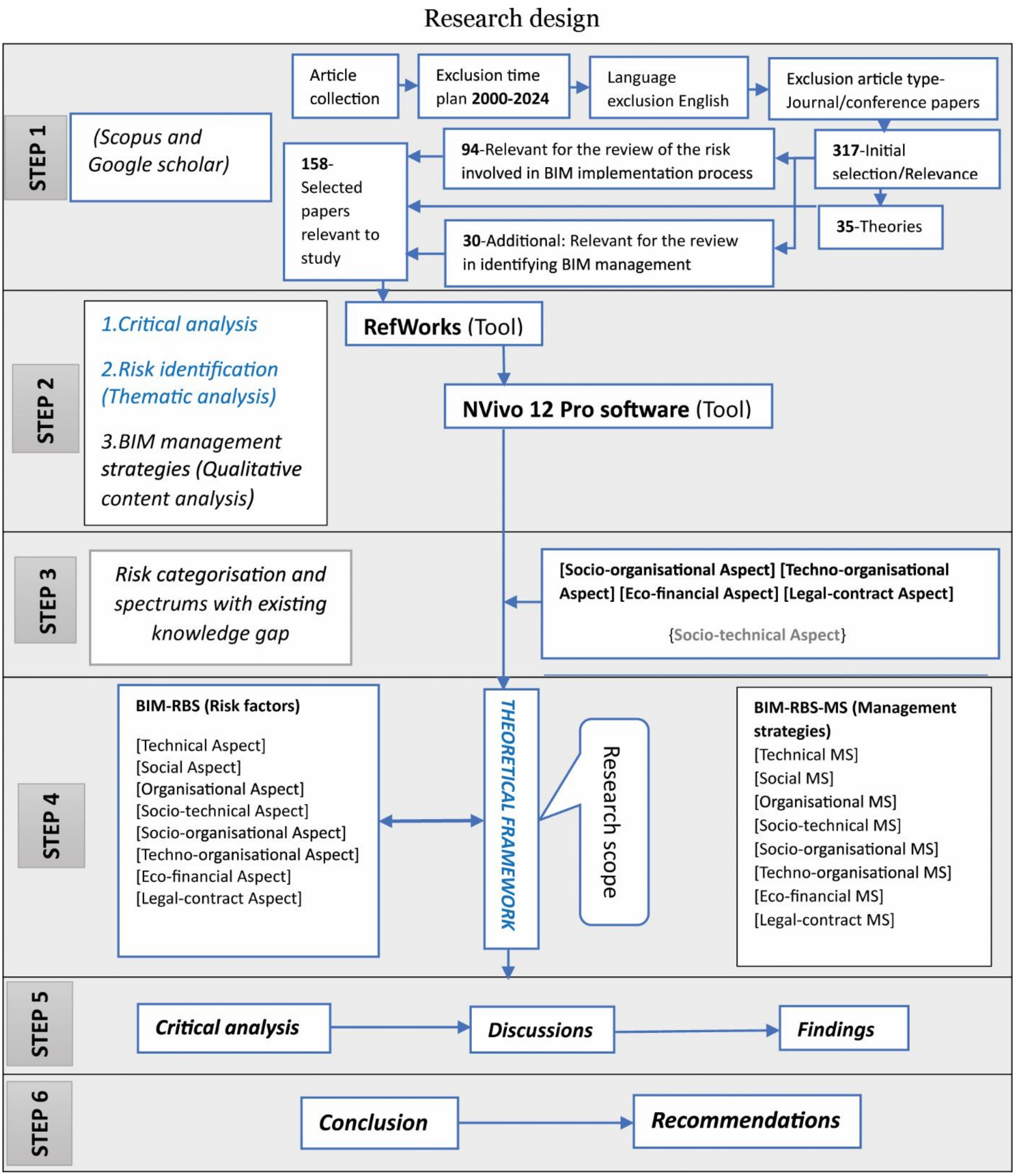

Figure 2 • Paper retrieval and research design process.

2.2. Risk identification and categorization

Risk identification is the first stage in risk management process [3], and risk categorization, which structures the diverse nature of risks, is widely accepted as an integral part of risk identification [82]. Both scholars and industry practitioners have adopted various risks identification tools such as risk list and risk map. However, RBS was chosen to develop a risk database for connecting appropriate strategies to risk factors, because it is highly ranked in the representation of risk factors in events and projects as identified by Ganbat et al. [32] and Zou et al. [30]. It is an open, flexible, and easily updatable framework. It can offer a global view of risk exposure and is widely used in research studies [30] and validated by Hillson [83] and Hamzaoui et al. [84].

Step 3: Categorization involves organizing information, and scholars categorize BIM risk descriptions in various ways. For example, Mat Ya'acob et al.'s [3] categorization technique comprises legal risk, financial risk, management and technical risk (i.e., single dimension), external risks (i.e., those that are outside the project and beyond the control of the project team such as economic, political, and climate conditions), internal risks (i.e., those that are within the project and can be controlled by the project team such as construction site, resources, documents, and project members) [30, 85, 86], and intra- and inter-organizational risks (i.e., managerial changes as BIM-based technologies affect both intra- and inter-organizational relations) [79, 86, 87]. This distinct approach enabled categorization of risks using RBS because different risks are present in different stages in BIM projects. In other words, regardless of the activity, there is always the possibility of a risk occurring, and the entire project may be affected depending on the type of risk and its severity [30]. Therefore, the factors considered in the categorization to develop "BIM-RBS" encompassed the technical, social, and organizational aspects from a single-dimensional boundary. This included further modifications into five aspects that are joined into two interrelated dimensional boundaries, namely the socio-technical, socio-organizational, techno-organizational, eco-financial, and legal-contract aspects. The rationale behind this categorization choice is that it covers and comprehends all the fragmented stages of a construction project such as the design, construction, and maintenance phases, including external risks. Additionally, this study seeks to examine the intersection of the two boundaries in detail. Given the limited research conducted in this area, the findings will enable scholars to explore these aspects individually by applying specific theories/ theoretical lenses, or frameworks developed from this study.

2.3. Theory/theoretical lens selection criteria

Step 4: To select a theory/theoretical lens suitable to investigate and comprehend the link between the dependent variable (i.e., BIM-RBS) and the independent variable (i.e., BIM-RBS-MS) in each spectrum, it was indispensable to examine the applicability of these theoretical concepts [45]. The method involved qualitative content analysis and classification utilizing NVivo 12 Pro software for coding. This process involved evaluating the content of the theoretical concepts and relating each aspect based on the level of applicability (i.e., where O = Not applicable; X = Least applicable; XX = Applicable; XXX = Most applicable). These theoretical concepts were extracted from NVivo 12 Pro software and presented on Microsoft excel spreadsheet. See the classification details below.

2.4. Development and application of the blueprint

To assist and guide research efforts, theoretical frameworks are developed because they enhance knowledge and information exchange and also merge relevant concepts into a descriptive or predictive model in this study [88]. These are as follows:

- BbCNs
- Leavitt socio-technical model (LSTM)
- Risk factors (BIM-RBS)
- Management strategies (BIM-RBS-MS).

These can support BIM studies [11, 44]. The qualitative content analysis approach enabled the selection of viable theoretical concepts established in **Table 1**. The critical evaluation of the literature presented these four relevant concepts mentioned above. By integrating these concepts, the blueprint emerges as the theoretical framework to examine the risk factors aligned with management strategies within all spectrums presented in **Figure 3**. It includes BIM Risk Breakdown Structure (BIM-RBS) and BIM-RBS Management Strategies (BIM-RBS-MS), which are organized into BIM-RBS-Triangles within the BbCNs system, providing the conceptual background. The LSTM is used as the theoretical lens to analyze all components. First, BIM-RBS encompasses the risk factors within the technical aspect, social aspect, organizational aspect, socio-technical aspect, socio-organizational aspect, techno-organizational aspect, legal-contract aspect, and eco-financial aspect. Second, BIM-RBS-MS comprises the management strategies (MS) in these categories. The LSTM is most suitable for the analysis of BbCNs, because its underlying principles closely reflect the working nature in the system and capable of explaining the challenges of modern STSs. Its explanatory influence increases by incorporating new components such as technical, social, and organizational aspects to create a modified model that better reflects on BIM-related systems [31, 43, 89]. Therefore, the extended version of the LSTM that incorporates "BIM-RBS Triangles" will provide the theoretical basis to examine all spectrums in BIM studies. This is because the fundamental principle of the model states that all the components are highly interrelated, and the system is in a state of equilibrium. Any event that causes a change in the system is an incident (i.e., risk factor). These incidents shift the system into a state of disequilibrium, which relates to the magnitude of the risk and is determined by the boundaries of the deep structure. Therefore, an intervention is required (i.e., management strategy) to move the system back to a new equilibrium state [31, 72]. **Figure 3** presents the model in detail, and **Figure 4** shows its application to research.

The advantage of implementing this model is that the adaptable design permits the substitution of theories/theoretical lens in alignment with distinct research objectives. For example, if the research focus is based on the technical aspect, then DeLone and McLean [68] IS success model replaces LSTM in the system, with the benefit of additional components from the social or socio-technical aspect. If the research focus is aligned with the social perspective, then ANT replaces LSTM in the system. Furthermore, if the research focus is associated with the organizational aspect, then ODT replaces LSTM. Hence, multiple options shown in **Table S1**, Supplementary materials can be selected depending on the research focus. Moreover, the LSTM is most suitable due to its core principles, as new components can be added to form a variance model that encapsulates all spectrums.

Table 1 • Theories/theoretical lens to examine all spectrum in BIM-RBS and BIM-RBS-MS nexus (the Leavitt socio-technical model (in bold) is the selected theoretical framework used to examine all spectrum in BIM-RBS and BIM-RBS-MS studies)

Theory	Category							
	Technical	**Social**	**Organi-zational**	**Socio-organizational**	**Techno-organizational**	**Socio-technical**	**Legal-contract**	**Eco-financial**
Grounded theory	X	X	X	XXX	XXX	X	XXX	X
Activity theory	O	XXX	O	XXX	O	X	XX	O
Theory of reason action and planned behavior	O	X	O	X	O	X	O	O
Organization development theory	O	O	X	X	O	O	O	O
Actor network theory	O	XXX	O	XX	O	XXX	O	O
Social network theory	O	XXX	O	XXX	O	XX	XXX	O
DeLone and McLean IS success model	XXX	O	O	O	XX	O	O	X
Push and grow models	O	O	XX	XXX	X	O	O	O
Adaptive structuration theory	XX	X	X	O	X	XX	O	O
Systems theory	XX	O	X	O	XX	XX	O	O
Constructivism theory	O	O	XX	XX	O	XX	O	O
Technology diffusion theory	O	O	XX	XX	XX	O	O	O
Contingency theory	O	XX	XX	XXX	O	XX	O	O
Information processing theory	O	O	O	O	X	X	O	O
Mediated action theory	O	XX	O	XX	O	O	O	O
Organizational discontinuity theory	O	O	XXX	XXX	XX	O	O	O
Technology-organization-environment theory	X	O	X	O	XXX	O	O	O
Socio-technical theory	X	X	O	O	O	XXX	O	O
Leavitt socio-technical model	**XX**	**XX**	**XX**	**XXX**	**XXX**	**XXX**	**X**	**X**
Contract theory	O	O	O	O	O	O	XXX	O
Finance theory	O	O	O	O	O	O	O	XXX
Organization theory	O	XX	XXX	XXX	X	O	O	O

Key: O, not applicable; X, least applicable; XX, applicable; XXX, most applicable.

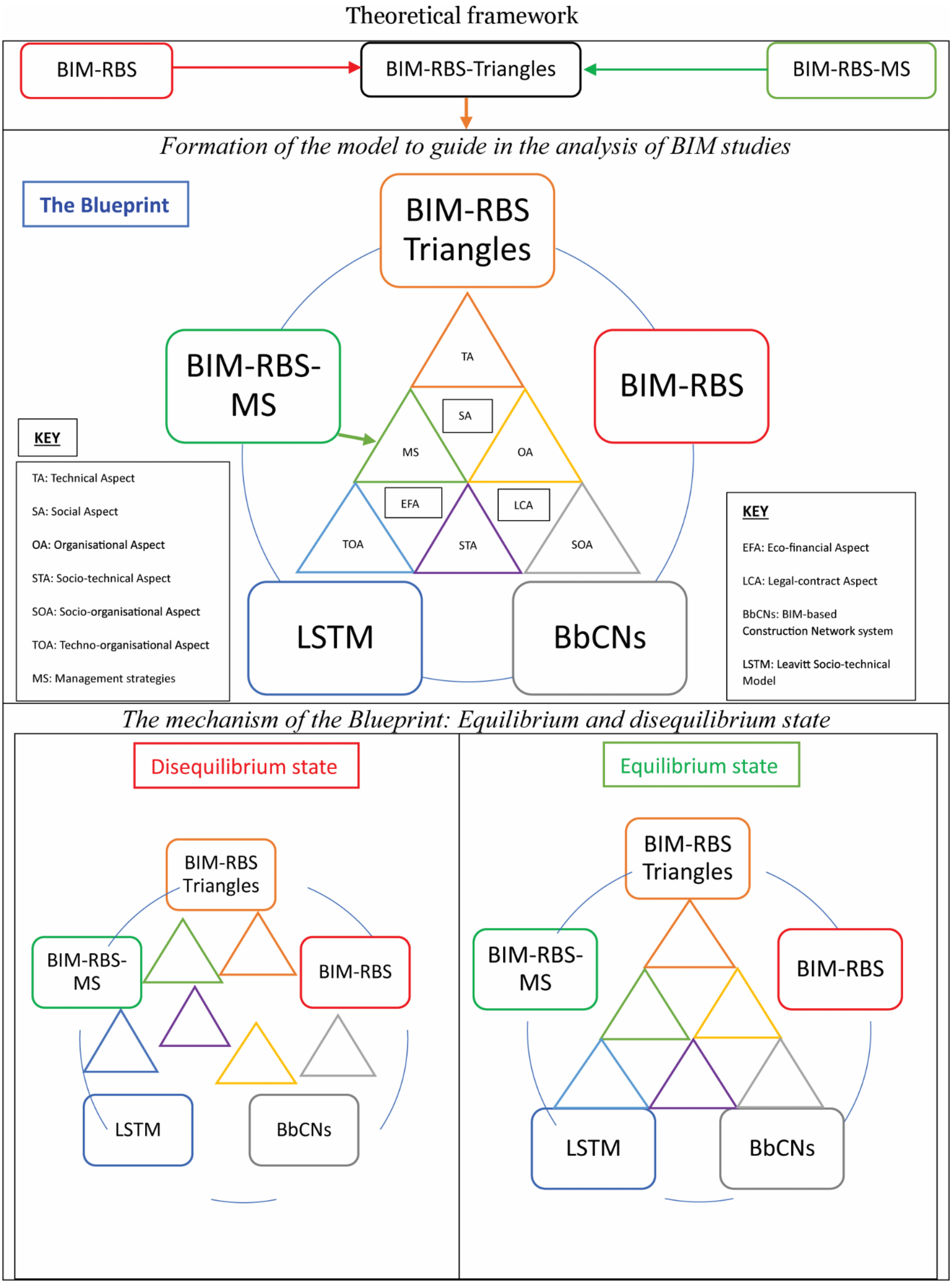

Figure 3 • Theoretical framework to assist in the analysis of Building Information Modeling risk factors and management strategies.

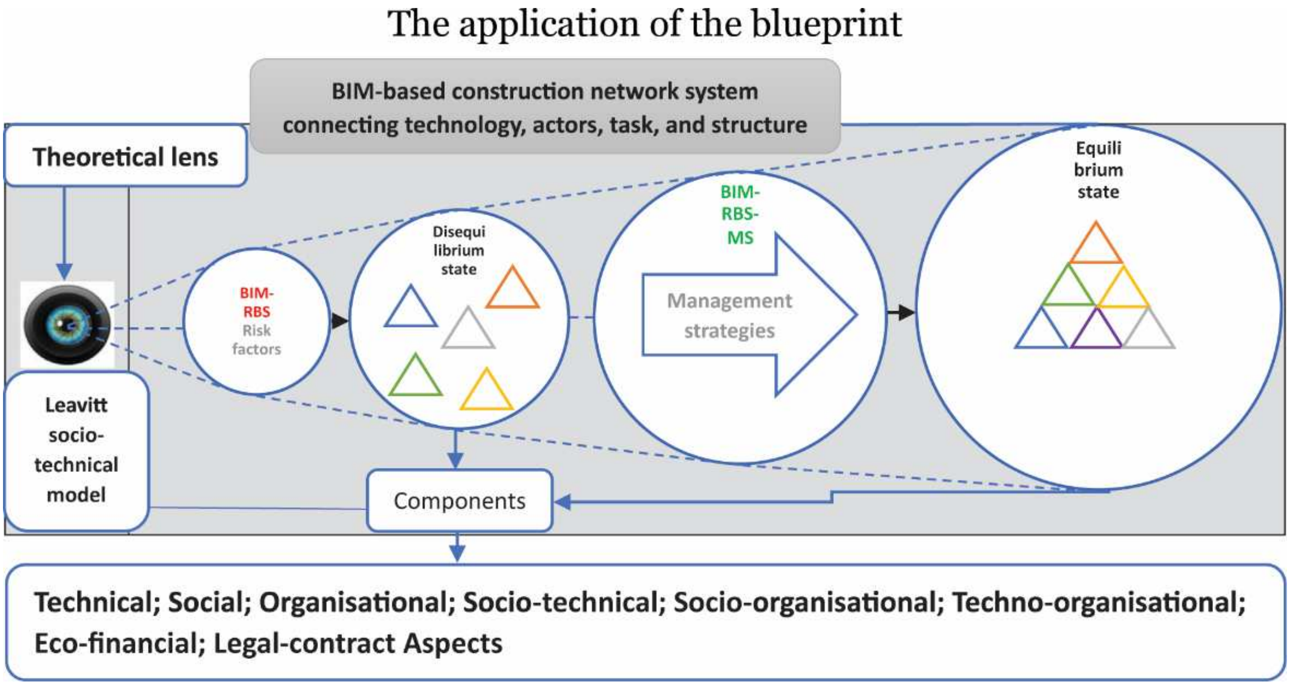

Figure 4 • The blueprint: theoretical perspective.

3. Analysis and discussions

Step 5: This section presents the analysis and discussions of the research. The review of previous BIM studies revealed the risks that are inevitable while implementing BIM. A holistic approach was adopted to categorize these risks to develop "BIM-RBS" for analyzing technical aspects related to the physical characteristics of the technology such as the tools (i.e., software, hardware, etc.), social aspects related to people's behavior, and organizational aspects related to the structure (i.e., inter- or intra-organizational links between departments and disciplines) from a single-dimensional perspective. From a multidimensional perspective, the socio-technical aspect refers to the interrelationships between the technical and social dimensions; the socio-organizational aspect addresses the connections between social and organization dimensions; the techno-organizational aspect focuses on the links between the technical and organization dimensions; the financial aspect relates to the economic consequences (i.e., eco-financial aspect); and the contractual aspect involves agreements designed to prevent legal issues (i.e., legal-contract aspect). As shown in **Figure S1**, Supplementary material, various Risk Categories are outlined. Therefore, the review enabled the establishment of a viable theoretical framework.

3.1. Aspects and capabilities in the use of BIM and the concept of the theoretical perspective result analysis

Analysis of risk factors and theoretical concepts is presented in **Table S1**, **Figures S1-S5**, Supplementary material and **Table 1** to examine BIM capabilities from a single-dimensional perspective and is discussed in detail in the following.

3.1.1. Technical aspect

The analysis suggests that industry professionals should be mindful of technical issues due to the complexity of BIM technology. The identified risk factors challenge McAuley et al.'s [90] argument that BIM improves coordination of all project information by providing a platform that connects all participants [91]. Interoperability issues are common and are directly linked to different standards of software not compatible with other systems. This will continue to be an unresolved problem due to BIM updates and integration with other components, even with the advancement in Industry Foundation Classes (IFC) products (i.e., lack of compatibility between standard-based IFC products). This is because the scope of interoperability ranges from the technical to the non-technical perspectives. This means that a continuous learning process is required to keep up with BIM updates, and these identified risk factors are likely to drive BIM systems into a state of disequilibrium, underscoring the need for further research to guide AEC professionals in effectively addressing these challenges. The most applicable analytical framework suitable to examine the technical aspect is DeLone and McLean's [68] IS success model that measures BIM's technical success. This theoretical framework was validated by Dowsett and Harty [69] by extending the model to evaluate the process of BIM implementation. The advantage of utilizing this particular framework is that additional components (i.e., from the social or socio-technical spectrum) can be included for extending the model, which substantiates its range of applicability. An alternative theory/theoretical lens that is applicable is the systems theory because it can identify interrelations between the system (i.e., BIM technology) and its external environment. It was validated by Yuan and Yuan [92]. They employed it as a theoretical framework integrating design methods encapsulating systems theory, cybernetics, and energy-saving design method for building consumption efficiency based on BIM. Furthermore, AST is another option because it can be used for analyzing situations of IT adoption in organizations, based on people's interaction with the technology. However, its applicability is more in the techno-organizational spectrum because the BIM technology is adapted to an organization and the organizational structures adapt to the technology.

3.1.2. Social aspect

These identified risk factors challenge the belief that BIM improves stakeholder's interoperability [93]. Based on social exchange theory, trust between organizations should influence the ability of project teams to adjust to uncertainties within exchange relationships [94], when using integrative technologies like BIM. Cultural resistance seems to be the dominant risk factor in this category, and scholars should investigate these risk factors from a lifecycle approach. Therefore, from a social perspective, the most applicable theoretical frameworks are activity theory, ANT, and SNT. The reason is that employing activity theory helps to understand the human mental functioning and action focusing on their culture, including social interactions that shape individual awareness. It also involves organizing the collective activities and was validated by O'Connor [47], Zahedi et al. [48], Levant [49], and Mäki and Kerosuo [50]. Meanwhile, ANT explains the interconnectivity of human and non-human elements and to what extent technology influences human behavior as validated by Poirier et al. [51], Lindblad [52], Fenwick [53], and Rowland [54]. SNT examines interactions between individuals' visualizing roles, relational patterns, and physical attribute, as validated by Al Hattab and Hamzeh [9] and Maskil-Leitan and Reychav [67] in relation to BIM implementation. There are other options, for example, mediated action theory, that can be applied to examine relevant aspects such as tension between participants in a system of relations, and their sociocultural and historical situations. Nevertheless, further validation of this theory is needed for investigating BIM implementation. Contingency theory is another option that examines relationships between structural and behavioral factors and how organizations function in their environment. However, it is more applicable to the socio-organizational spectrum.

3.1.3. Organizational aspect

BIM facilitates information sharing and enhances project value through integration and collaboration [95]. However, majority of the risk factors are not aligned with Zheng et al.'s [95] findings, potentially destabilizing BIM systems. Further research is necessary to establish equilibrium-seeking strategies. Therefore, to examine these risk factors aligned with strategies from an organizational perspective, the most applicable theoretical framework is the ODT because it identifies how boundaries impact communication and coordination challenges encountered by project stakeholders. Mignone et al. [96] validated this theory when they studied collaboration in BbCNs. Additionally, the organizational theory provides insights into how individuals or groups behave and interact to achieve a common goal. Alternative applicable options are contingency theory and constructivism theory for reactive and proactive processes in change management.

Analysis of risk factors and theoretical concepts is depicted in **Table S1**, **Figures S1, S2**, and **S6-S10**, Supplementary material and in **Table 1** to examine BIM capabilities from an amalgamated dimensional perspective and is analyzed in detail in the following.

3.1.4. Socio-organizational aspect

The critical analysis in this study highlights risk factors that could destabilize BIM systems, which contradicts the view that BIM positively influences project participants' behaviors by promoting collaboration and communication [97]. Therefore, extensive research is imperative to discover management strategies in this context, especially regarding the interplay between knowledge domains, considering limited reference materials. Based on the boundary between the social and organizational dimensions, the most applicable theoretical frameworks to examine this spectrum are activity theory, SNT, Push and Grow model that acknowledges people's individual feelings, aspirations, and assumptions when engaged in a change management process. Contingency theory validated by Olugboyega and Windapo [98] proposes a strategic and contingent BIM application model for construction projects. ODT and organizational theory highlight how boundaries affect communication and coordination issues encountered by project stakeholders. Alternative applicable options are ANT and constructivism theory, which were validated by Blay et al. [64], and they investigate benefits, challenges, and opportunities in managing changes in BIM-Level 2 projects. Technology diffusion theory explains how, why, and at what rate new ideas and technology spread within organizations. Mediated action theory explains how people utilize all kinds of objects and tools, both physical and psychological, to structure their thought, and interact and communicate with each other.

3.1.5. Techno-organizational aspect

BIM could provide solutions for organizational and technological challenges facing the AEC industry according to Dossick and Neff [79]. However, the risk factors suggest otherwise. Nevertheless, the boundaries of the two knowledge domains lack comprehensive research, leading to a shortage of reference materials. Future research is crucial to comprehend and tackle challenges within this category. Therefore, to examine the intersection of the technical and organizational boundaries, the analysis indicates that the most applicable theoretical framework is TOE theory. It describes factors that influence technology adoption in the organizational, environmental, and technological contexts that include the internal and external technologies relevant to an organization. It was validated by Wan et al. [99] as a framework to examine BIM adoption challenges from a contractor's perspective. Alternative applicable options are the DeLone and McLean [68] IS success model and systems theory because they identify processes that explain how a system retains its functions while continuing to integrate new information. ODT and technology diffusion theory were validated by Yuan and Yang [100] to investigate BIM adoption based on government subsidy.

3.1.6. Socio-technical aspect

Lack of BIM training is a major problem associated with the risk factors because practitioners' early adoption of BIM follows the "learn on the job" approach tailored to their organization's skills and knowledge according to Georgiadou [1]. Therefore, further research is needed to develop equilibrium-seeking strategies. The analysis indicates that the most applicable theoretical framework in this category is the socio-technical theory, which explains the interrelatedness of social and technical aspects of an organization and was validated by Sackey et al. [43], Klein [55], Golden [56], Walker [57], and Miner [58], followed by ANT. Supplementary applicable options are SNT, systems theory, constructivism theory, contingency theory, and AST. These focus on the types of structures that are provided by advanced technologies and the structures that actually emerge in human action as people interact with these technologies. These were validated by Chen et al. [101] for exploring the interaction between BIM technology and the business process in a construction organization.

3.1.7. Legal-contract aspect

Sabo and Zahn [15] highlighted legal issues in BIM technology implementation, and current analysis confirms persisting challenges due to lack of effective management strategies. Nevertheless, challenges persist regarding liability in data sharing, without clear strategies in place. Guidelines like those from the Joint Contracts Tribunal (JCT) and New Engineering and Construction Contract (NEC) inadequately addressed legal concerns in BIM projects [102]. Therefore, further research is imperative because the analysis from the in-depth review suggests that there is no descriptive or normative theory that explains what the law is and what it should be with regard to contract laws that comprehend a broad domain like BIM implementation. However, a conceptual framework that encapsulates the aspects of contract theory, tort theory, theory of contractual relationship management, and contractual theory of corporation is an applicable theoretical framework because it explains how people and organizations construct and develop legal agreements, followed by SNT. Alternative applicable option to be considered is activity theory.

3.1.8. Eco-financial aspect

Tsai et al. [103] and Al-Otaibi [104] emphasized the cost-saving benefits of BIM, but their analysis revealed the potential risk factors contrarily. Therefore, further research is essential to minimize these risk factors because the knowledge gap in this area of study can be exploited to maximize returns, as a lesson for business owners and professionals. Finance theory explains the value of an equity share that is determined by its fundamental value and the expected discounted value of its future yield or dividends, and the analysis suggests that it is the most applicable theory in this category. However, it is based on various theoretical models because traditional finance theory tends to focus on cross-sectional diversification of risk, which can inspire innovative activities.

3.2. Discussions

The critical examination of BIM and other IT-related studies assessed by various scholars (e.g., [31, 39, 40, 69, 72, 99]) employing various theoretical concepts sheds light on, as well as significantly advanced, the understanding of risk factors in BIM implementation and applicable theories/theoretical lens. The term embraced BIM-RBS outlined specific dimensions of risk factors, and to further examine the interrelations with management strategies, BIM-RBS-MS is pivotal. Therefore, an in-depth review approach was employed, facilitating the processing of retrieved papers on BIM and other IT-related studies. This approach was instrumental in establishing risk factors from a single-dimensional perspective extending to the amalgamated dimensional aspect with the theoretical framework that can subsequently be applied to guide BIM research studies.

The established robust theoretical framework, as depicted in **Figures 3** and **4**, stands as a substantial theoretical contribution of notable significance. Its adaptable design allows the replacement of other theories/theoretical lens for encouraging multiple options in alignment with distinct research objectives, and accentuates its practicality and versatility within the research paradigm.

Furthermore, the qualitative methodology, leveraging NVivo 12 Pro software for coding, demonstrated its effectiveness. This approach facilitated the establishment of "BIM-RBS", systematically categorizing risks inherent across disparate construction stages, and proffered theories/theoretical lens aimed at investigating their impact and alignment with appropriate strategies. This functionality positions the theoretical framework as a pivotal tool for both understanding and actively investigating not only risks within the context of BIM implementation but also mitigating strategies.

The practical implications of this study are profound because the developed "BIM-RBS" provides a valuable repository of risk factors that can serve as a "check and balance mechanism" and a knowledge base guiding AEC professionals to avoid risks. Additionally, it provides a valuable theoretical framework to assist academic professionals in BIM studies. The potential for generalization and application of "BIM-RBS" and "the blueprint" is substantial and extends beyond its immediate utility by diverse professional disciplines adaptable to other fields. The novel theoretical framework composes an exceptional knowledge contribution to the field, demonstrating its potential for global applicability.

4. Findings

This article revealed issues such as interoperability; cultural resistance, disciplines in various locations, intellectual property rights, high initial BIM cost, and mistrust within team members. It clearly shows the complexity of the technology, indicating that BIM implementation is still a challenge. The theoretical findings suggest that the DeLone and McLean [68] IS success model is an appropriate theoretical framework to examine BIM implementation from a technical perspective and its ability to allow new components added to form a variance model consisting of other constructs. From a social perspective, there are three appropriate options, namely activity theory, ANT, and SNT, that provide a comprehensive opportunity for scholars based on their research objectives. Organizational theory and ODT are most appropriate to examine the organizational aspects because they specifically relate to the boundary associated with the knowledge domain. Socio-technical theory is most applicable for the socio-technical spectrum because technology and people in a work system are highly interdependent. However, other options are available such as ANT. The study revealed from a socio-organizational perspective that there are more options, even though limited research is conducted within the knowledge domain. No research was conducted associated with the techno-organizational aspect revealing three most applicable options with alternative applicable options that researchers can select from, but TOE theory is the most suitable option. The legal-contract aspect has few options such as contract theory and tort theory due to limited research conducted in this category. The eco-financial aspect has the least options due to limited research on BIM evaluation utilizing these theories. There is the need for scholars to validate these theoretical models for investigating BIM. Grounded theory provides the opportunity for researchers to develop theories within the context of these knowledge domains. The proposed option is the LSTM to include all spectrums enabling the establishment of the "blueprint" model.

The findings based on the selection criteria in each spectrum from a single-dimensional aspect are presented in **Figure 5** and the amalgamated dimensional aspect in **Figure 6**.

4.1. Limitations of the findings

Despite the invaluable insights offered by this study, it is imperative to acknowledge certain inherent limitations. For example, data validation via interviews and surveys that involve specific case studies was not included. The reference materials used were academic publications obtained from an online source. These are limited to Scopus and Google Scholar, and hence, may not fully capture the complex and dynamic challenges present in actual construction projects. Additionally, some identified theories/theoretical lenses were not validated by scholars investigating BIM on actual projects, especially the financial theories due to limited research addressing BIM evaluation from a financial and economic perspective. Constructivism theory, mediated action theory, and push and grow models were not validated in BIM studies, including organizational theory and organization development theories, because there are different types to be considered. Furthermore, contract theory, contractual theory of corporation, tort theory, and theory of contractual relationship management explain contract laws to address the contractual and legal aspect in the context of BIM implementation issues. To address these limitations, future research endeavors should prioritize validation in BIM studies through case studies via interviews and observations.

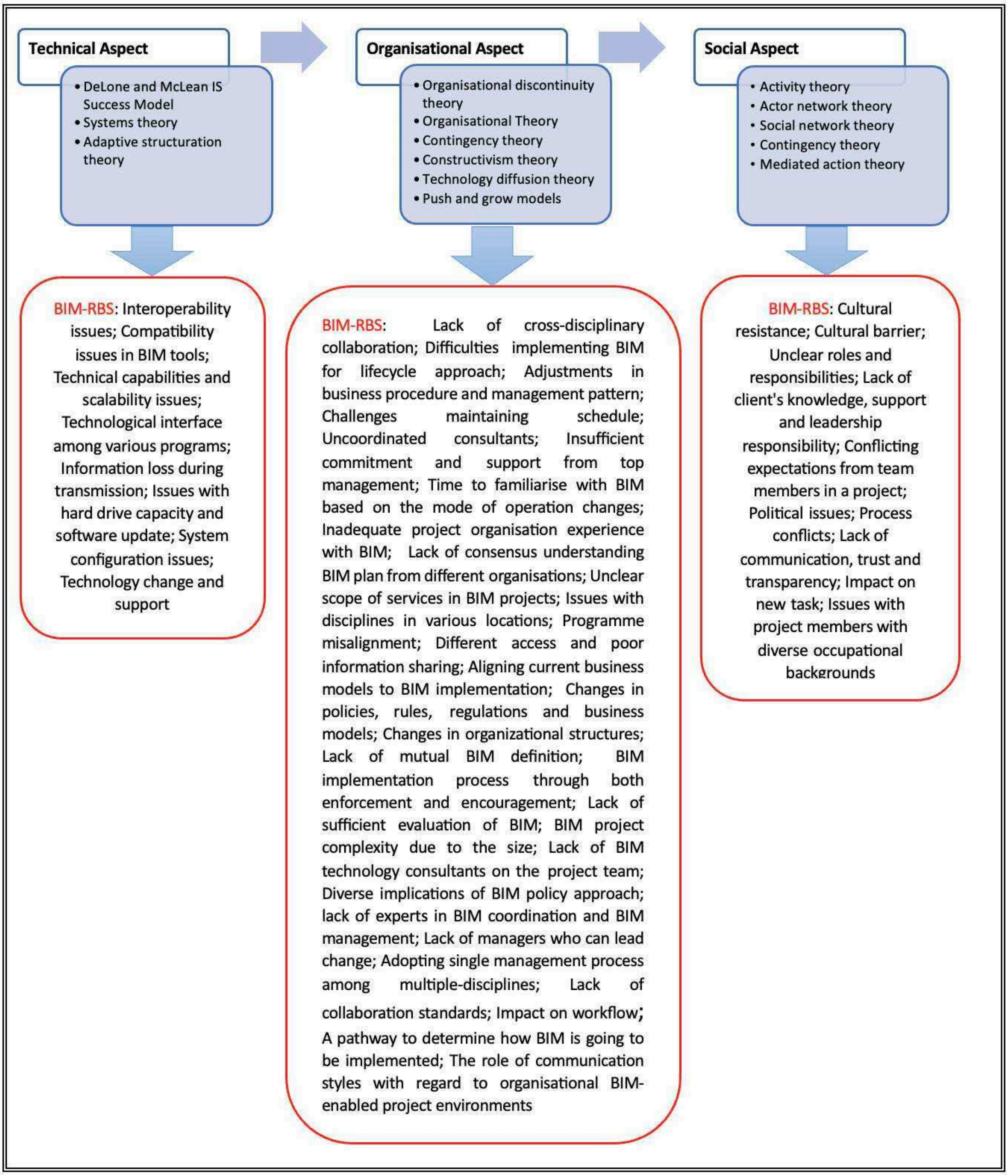

Figure 5 • Risk factors and theoretical concepts to examine Building Information Modeling capabilities from a single-dimensional perspective

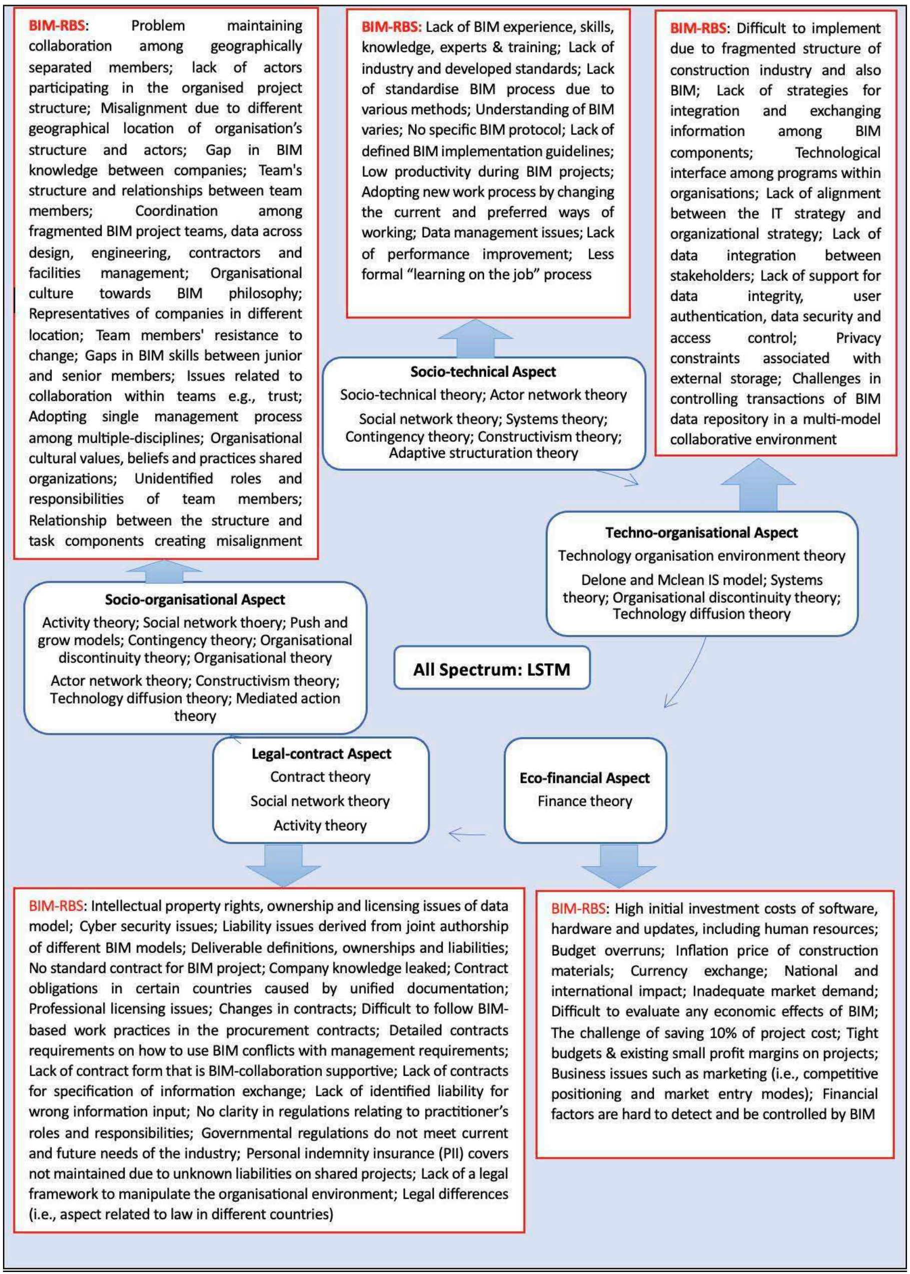

Figure 6 • Risk factors and theoretical concepts to examine Building Information Modeling capabilities from an amalgamated dimensional perspective.

5. Conclusions and recommendations

This study provides a comprehensive assessment of the interrelationship between risk factors and management strategies in the implementation of Building Information Modeling (BIM). By examining key challenges in BIM adoption and implementation, this article revealed issues such as compatibility issues between BIM tools, cultural barriers, challenges in maintaining project schedules, cyber-security threats, budget overruns, and mistrust among team members. The study also highlights critical issues that the AEC industry must address.

The novelty of this research lies in its development of a comprehensive, multidimensional framework that integrates diverse theoretical perspectives, offering a holistic approach to analyzing BIM implementation. The theoretical frameworks identified and utilized to examine each dimension are a significant innovation in this study. From the technical perspective, the theoretical frameworks identified to analyze each dimension of BIM adoption are the DeLone and McLean [68] IS success model chosen for its capability to measure BIM's technical success. The activity theory provides insights from a social perspective, understanding how human activity and collaboration are shaped by history and culture. ODT, from an organizational perspective, identifies how boundaries impact communication and coordination challenges. Additionally, the socio-technical theory addresses the socio-technical perspective, bridging human and technological factors, while SNT explores socio-organizational dynamics in a BIM project. From a techno-organizational perspective, TOE theory was selected to assess how organizations adapt technology in the context of their environment. The finance theory covers the eco-financial aspects, addressing economic risks and opportunities related to BIM, and the contract theory tackles legal-contractual perspective, ensuring the mitigation of legal risks through effective agreements.

This comprehensive framework represents a state-of-the-art theoretical framework and a sound approach to understanding BIM implementation. By integrating BbCNs as the conceptual foundation with BIM Risk Breakdown Structure (BIM-RBS) and BIM-RBS Management Strategies (BIM-RBS-MS) as the key variables, and applying the LSTM as the theoretical lens (**Figures 3** and **4**), the study creates a robust tool for industry professionals. This integrative framework provides deeper insights into managing the inherent complexities in BIM implementation, especially within collaborative environments that involve technical, social, organizational, and legal factors.

The global significance of this research lies in its ability to shape future BIM-related practices and policies. The framework offers practical applications for the AEC industry, enabling enhanced project coordination, better risk management, and improved project outcomes. Furthermore, its comprehensive nature makes it a vital tool for policymakers, supporting the development of BIM standards that emphasize transparency, interdisciplinary collaboration, and sustainability.

In conclusion, this study contributes significant novelty by combining a broad range of theoretical perspectives to produce a comprehensive framework for BIM implementation. It emphasizes the importance of a multidimensional approach, addressing risks from technical, organizational, socio-technical, and legal angles. This framework has the potential to serve as a critical resource for both industry practitioners and researchers, guiding future BIM adoption strategies globally. Further research is recommended to refine and expand this framework, ensuring its relevance and adaptability to the evolving challenges faced by the AEC industry.

5.1. Recommendations

More work can be done to the existing research, particularly at the intersection of two knowledge domains clearly shown in Step 3 of the research design. Further exploration in this area is essential to align appropriate management strategies to the identified risk factors. Furthermore, employing grounded theory to establish theories for evaluating the eco-financial spectrum and legal-contractual spectrum is recommended. This includes verifying unvalidated theories/theoretical lens in real-life BIM projects to address the limitations earlier discussed.

Acknowledgments

We are grateful for the support of Prof.Waqar Ahmed. The authors are grateful for his enthusiasm, knowledge, expertise, and guidance in innumerable ways during discussions over this research.

Funding

The authors declare no financial support for the research, authorship, or publication of this article.

Author contributions

Conceptualization, A.E. and I.D.; methodology, A.E. and I.D.; software, I.D.; validation, A.E and I.D.; formal analysis, I.D.; investigation, I.D.; resources, I.D.; data curation, I.D.; writing—original draft preparation, I.D.; writing—review and editing, A.E.; visualization, A.E. and I.D.; supervision, A.E.; project administration, I.D. Both authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Institutional review board statement

This study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the University of Lincoln Ethics Committee. The research project titled “A Framework for Identifying the Link between BIM-RBS Management Strategies and BIM-RBS Risk Factors” (Review ref. 2021_7067) received a favorable ethical opinion on 17 September 2021.

Informed consent statement

Not applicable.

Supplementary materials

The supplementary materials are available at https://doi.org/10.20935/AcadEng7392.

Additional information

Received: 2024-06-27

Accepted: 2024-10-15

Published: 2024-11-15

Academia Engineering papers should be cited as *Academia Engineering 2024*, ISSN 2994-7065, https://doi.org/10.20935/AcadEng7392. The journal’s official abbreviation is *Acad. Engg.*

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