

A PATH WITH NO OBSTACLES LEADS TO NOWHERE: AN FCM BASED MODELLING OF CONSEQUENCES OF OBSTACLES ON BIM APPLICATION IN ARCHITECTURAL DESIGN

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SUMMARY: Building Information Modeling (BIM) has revolutionized construction, yet its success in the architectural design phase remains hindered by interrelated obstacles. Using Fuzzy Cognitive Mapping (FCM) and expert input from a large-scale commercial project in Iran, this study models the causal relationships among 23 obstacles, 10 intermediate consequences, and the triple constraint (time, cost, quality). Drawing on expert knowledge from a large-scale commercial project in Iran, static (max-min path analysis) and dynamic (iterative activation until equilibrium) analyses were performed. Key findings reveal that 'lack of teamwork mentality' (E4) consistently emerges as the most critical intermediate consequence across all scenarios (final activation 0.58–0.65). Environmental obstacles exert the strongest negative influence on project cost (0.65) and time (0.63), while human-related barriers — particularly lack of compatible standards and guarantees for smaller projects — dominate in the real-case validation. Scenario simulations demonstrate that activating environmental obstacles produces the highest equilibrium values on the triple constraint, whereas organizational and human obstacles most strongly amplify reduced productivity and lack of teamwork mentality. The resulting FCM provides a quantifiable, decision-support framework for prioritizing mitigation strategies in BIM implementation during architectural design. These insights advance understanding of obstacle propagation dynamics and offer actionable guidance for practitioners and policymakers in developing and emerging construction markets.

KEYWORDS: Building Information Modeling (BIM), Obstacles, Architectural Design, Construction Industry, Fuzzy Cognitive Map (FCM).

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1. INTRODUCTION

Construction is a fundamental, critical, and complex industry in development of societies. One of the common concerns among project stakeholders is proper and effective management of time, cost, and quality, such that in most cases, these three indicators are prioritized in the ranking of projects for implementation and completion and sometimes the basis of measurement of the project success. Building Information Modeling (BIM) supports planning, designing and budgeting of the project, and provides a platform to help architects improve the evolutionary design process to increase the design speed and quality. BIM is a comprehensive computer-based information system of building details. BIM, as a tool for facilitating architects' performance, reduces design and management errors during and after the implementation, increases building productivity, and reduces project implementation and operational issues (Butt, Naaranoja, & Savolainen, 2016; Waqar, Othman, & Mansoor, 2024). BIM helps architects reduce consequences of stakeholders' improper decisions and improves project design management by providing a better picture of project reality (Allban, 2024; Lahdou & Zetterman, 2011).

Considering benefits of BIM models throughout project life cycle, and with increasing popularity of BIM platforms, it is now possible to use it to develop basis for synchronization and application of various building information resources as early as conceptual and architectural design phases (Dave, Buda, Nurminen, & Främling, 2018; Dave, Kubler, Främling, & Koskela, 2016; Wang, 2012). According to the general view shown in the studies, most of research projects are towards identifying and listing these obstacles with a one-level approach (Al-Zwainy, Mohammed, & Al-Shaikhli, 2017; Babatunde, Udeaja, & Adekunle, 2020; Bosch-Sijtsema, Isaksson, Lennartsson, & Linderoth, 2017; Chan, 2014; Hamidi Monozam, Monazam, Hosseini, & Zaeri, 2016; Hatem, Abd, & Abbas, 2018) and mostly without considering the effects or interactions among these obstacles. Since the implementation of BIM in projects requires fundamental changes in all traditional methods since the beginning of projects, construction stakeholders should consider comprehensive and continuous planning for its establishment.

systematically identify, categorise and — through the application of Fuzzy Cognitive Mapping (FCM) — model the causal interdependencies among obstacles to BIM application specifically in the architectural design phase, together with their principal intermediate negative consequences, and to quantify both their direct and indirect impacts on the conventional project success criteria of time, cost and quality. By developing and validating the first multi-layer FCM tailored to this context, the work provides a granular, quantifiable decision-support framework capable of revealing how environmental, organisational, human, and technological barriers propagate through intermediate effects to influence project outcomes. Like any other changes, the application of new technologies such as BIM will result in stakeholders facing different obstacles. The larger the scale of projects and the greater their complexities are, the more BIM benefits are reflected in them, and the more important is the need for special attention to resolve the obstacles and their consequences on BIM application (Brahmi & Sassi-Boudemagh, 2024; Jadidoleslami & Saghatforoush, 2026; Pei Tang, Amlan Mukherjee, & Onder, 2010).

In the following, after introducing the generalities of the BIM concept and its application in architectural design, the obstacles to BIM implementation in the architectural design and their consequences are reviewed.

2. LITERATURE REVIEW

BIM is widely used in many developed countries as a solution or emerging method to increase the accuracy, understanding, and speed of construction. Currently, the United States, Britain, Finland, Denmark, Norway, Hong Kong, and Singapore have implemented this method in their private and public sectors. In recent years, the use of BIM has influenced the success of many projects, particularly in the architectural design phase. Therefore, it is crucial to understand the role of BIM in architectural design development to identify and analyze the obstacles to its implementation by considering dynamic effects of obstacles on each other, and on time, cost and quality factors. In this section, the BIM's position in architectural design is discussed, and existing literature on obstacles to BIM application in the architectural design are reviewed.

2.1 BIM in architectural design

BIM has been introduced since 2002 in the context of technological developments; and now, after more than two decades, it has reached a prominent position at the international level. The philosophy of this method is based on optimization of a comprehensive digital model of building and its application at all stages of project life cycle (Jadidoleslami & Saghatforoush, 2026; Saghatforoush, Hosseini Nourzad, Zareravasan, & Jadidoleslami, 2023).

BIM is a computer-based modeling technology used for managing and generating building information and its analysis (Butt et al., 2016; Toyin & Mewomo, 2023). According to the definition presented by the American National Building Information Modeling Standard (ANBIMS), BIM is a digital representation of the physical and functional characteristics of a structure and is a shared source of knowledge for a structure and a reliable basis for decision making during its life cycle (Jadidoleslami, Azizi, Sobhiyah, & Zareravasan, 2025). The fundamental hypothesis of BIM is helping stakeholders, including architectural designers, at different stages of a structure life cycle from the beginning of its setup and updating to its completion, to make it possible to reflect on the tasks of a stakeholder. Using the BIM allows stakeholders to have a realistic view of the future to see the final design in an nD shape model, to understand what is going to be delivered. Having a database for projects assists in better decision-making (Lahdou & Zetterman, 2011).

By using such a database, the design speed can be increased, as fewer communication is required. Visualizing the construction process through an nD model enhances the understanding of processes significantly and helps identify construction issues and possible problems in the building operation process. This is an effective method to improve the design and quality of documents and helps to increase cost estimations accuracy by 3%. BIM can be cooperative in helping construction practitioners to conduct small or high-risk projects. If it is performed successfully, it can prevent various duplications (Cho et al., 2011).

CAD is merely a 3D display of 2D designs, and unlike BIM, it is not intelligent. In fact, the CAD system cannot detect errors automatically. However, BIM is a modeling system based on a database. The design process in BIM starts with development of a model consisting of intelligent components that represent doors and windows, ceilings, beams, stairs, air conditioning system, wiring, and so on. These components and their relationship with each other are defined and all information related to the features of each component is stored and by applying any changes in its features, it adapts itself with the new design. Using BIM, the components of the building can be designed and changed if necessary. These changes are applied at all stages of the project. In such a way that at the same time with the design of the plan, the height, cross-section, and details of the building are made, and any changes are applied automatically and simultaneously at all aspects of the model. Moreover, BIM allows us to store key project information in the model; while in traditional systems, this information was stored using notes (Krygiel & Nies, 2008).

The main difference between CAD and BIM model is that in the CAD system, all drawings are prepared separately and state the building characteristics only. However, in BIM, all information is gathered in one model, and all drawings are extracted from it, and all components are defined with real characteristics and are linked to each other. BIM has many benefits for projects, including resolving many construction problems such as delays, design interferences, duplications, lack of coordination among project components (Latiffi, Mohd, Kasim, & Fathi, 2013).

BIM is one of the most promising developments in the architecture, engineering, and construction (AEC) industry. In BIM, a virtual model of the building gets created. Such a computer-based model contains the accurate information and geometric shape required for supporting the construction, production, and supply activities, through which the building is built. Moreover, BIM coordinates many of the functions required for modeling the building life cycle by providing a basis for changes and new design and construction capabilities in the drawings and relationships between the project team. When BIM is appropriately applied, it develops a consistent design and construction process, which results in buildings with higher quality, lower cost, and shorter construction time (Eastman, Eastman, Teicholz, & Sacks, 2011; Eze, Aghimien, Aigbavboa, & Sofolahan, 2024; Parsamehr, Perera, Dodanwala, Perera, & Ruparathna, 2023). Since the BIM implementation in projects requires major changes in all traditional methods, it is expected that like any other change, applying these changes face many obstacles and resistance. In the following, the issue of obstacles to proper BIM implementation is addressed.

2.2 Obstacles to BIM implementation in the architectural design phase

The introduction of BIM into the construction industry promises dramatic developments in this industry and replaces traditional current processes in projects. The construction industry practitioner acknowledges its slowness and low productivity. The wide range of BIM use, which supports the entire process of building life cycle and reduces costs and time and improves various work processes, has made the employers, consultants, and contractors to take advantage of it. The obstacles to BIM implementation have caused a lack of using full potentials of BIM up to now. Identifying and analyzing these obstacles helps providing solutions to resolve them. Many studies have

been conducted in this regard, but the obstacles in the architectural design phase have not been evaluated in a purposeful way.

Yan et al. (2008) identified these obstacles through a historical review of literature and case studies conducted on experts in this field in developed countries, and throughout the building life cycle. According to the results of this study, the main five obstacles were the adequacy of the current technology, individuals' refusal to learn new technology, being inappropriate for all projects, waste of time and human resources, and the high cost of copyright and training. The obstacles related to training and learning as well as costs for BIM implementation in the architectural design phase are observable.

Sawhney et al. (2013) conducted a comprehensive study in India to identify the obstacles to and stimuli of BIM implementation. In this research, emphasizing the lack of literature in the field of BIM in India, at first through a semi-structured interview with industry experts involved in BIM projects and based on the findings of this qualitative research and literature review, in the second phase a web-based survey was conducted that was aimed to address a wide range of industry experts. After data collection and analysis, it was found that the main obstacles were related to the impact of teaching and learning, fear and resistance to change, and lack of technical skills. These obstacles significantly affected the BIM implementation in the architectural design phase.

Kekana et al (2014) identified the existing obstacles in the South Africa through a literature review. Delegation of professional responsibility for design and intellectual property of the output of this stage and lack of necessary standards for applying BIM were among the significant obstacles addressed in this study. The existence of any of these obstacles from the beginning of the design may make the use of BIM difficult.

In Iran, Hosseini et al. (2015), conducted a study through a field study and distribution of questionnaires among experts and found that the most important obstacles to BIM are related to the structure of the Iranian market, the nature of the construction industry, and the business environment in this country, and lack of attention of policymakers and the government. It seems that the identified obstacles in this study, such as lack of knowledge about the process of BIM adoption, lack of appropriate infrastructure, lack of support of managers to change the current methods, and lack of standards and practical guidelines for BIM approval in Iran influences the design phase most. Similarly, in the study conducted by Liu et al (2015) , to identify the obstacles in the AEC industry, six main obstacles are identified and prioritized through a literature review and a survey. These obstacles included lack of tendency to share information in BIM, high initial cost of software, high cost of the implementation process, lack of experts, and high cost of teaching and learning have a significant negative effect on BIM implementation in the architectural design phase.

Oteng et al. (2018) evaluated the obstacles to BIM implementation in developing countries. In this study, using purposeful sampling method, about 300 questionnaires were distributed among experts in the field of BIM in Ghana. The identified obstacles were classified as human resources, technical issues as well as contractual, economic, and managerial issues. A similar study was conducted by Siddiqui et al. (2019) in Pakistan. The main identified obstacles included lack of skilled personnel, unwillingness of stakeholders to share information, legal and security issues related to software, and high cost of BIM implementation. It is obvious that these obstacles in the architectural design phase and at the beginning of using BIM, are undeniable. Siebelink et al. (2020) evaluated these obstacles from a different perspective in terms of their effect on the organizational level in relation to BIM maturity. In this study, using multiple cases, the existing obstacles, and their effect on various organizational levels (including senior management to project teams) were examined and important obstacles included motivational obstacles to BIM application, competence, and time capacity of individuals at all levels of an organization and obstacles at the middle management level such as lack of support of top management. In this study, the existence of obstacles is considered as a brake on the maturity of BIM at the organizational level. The interesting point in this study is that the obstacles identified in previous studies, such as high cost of the implementation process, lack of experts, and high cost of teaching and learning in BIM implementation and resistance to change, which were limited to the project level, still were of great significance at the organizational level.

In this study, through in-depth review of literature, classification of the obstacles to BIM implementation in the architectural design phase is performed, and 23 obstacles are identified in Appendix 1 accordingly.

There are some studies that address the impact of obstacles to BIM implementation on various aspects of the projects, including time, cost, and quality (Bosch-Sijtsema et al., 2017; Hamma-adama, Kouider, & Salman, 2020; Nsimbe & Di, 2024; Oraee et al., 2019; Siddiqui et al., 2019); In these studies, lack of quantitative based analyses

that could address the consequences of obstacles on BIM application in various aspects of the project, including time, cost, and quality is evident. In the continuation of this study, using a literature review, the impacts of obstacles to BIM application on time, cost, and quality are assessed. Ten effective factors are prioritized in the Table 1.

Table 1 systematically outlines the negative impacts that can arise when implementing BIM in the architectural design. Each entry, labeled E1 through E10, identifies a specific obstacle encountered during BIM application, along with references to scholarly articles that have discussed these obstacles. Mentioning these factors in the article emphasizes the importance of overcoming these obstacles to fully harness the benefits of BIM in architectural design. The references provide empirical evidence and further reading for those interested in studying the consequences in more detail. This table serves as a warning and a guide for professionals to anticipate and mitigate these issues for successful BIM implementation.

Table 1: The impacts of obstacles to BIM implementation.

Id	Title	References
E1	Increasing errors and omissions	(Babatunde et al., 2020; Demeke Wasse & Dai, 2024; Sawhney & Singhal, 2013; Siddiqui et al., 2019)
E2	Increasing conflicts during construction	(Babatunde et al., 2020; Sawhney & Singhal, 2013; Siddiqui et al., 2019)
E3	Unestablished working collaboration between stakeholders	(Babatunde et al., 2020; Kineber et al., 2023; Matarneh & Hamed, 2017; Oraee et al., 2019; Siddiqui et al., 2019)
E4	Lack of teamwork mentality	(Farouk, Zulfhisham, Lee, Rajabi, & Rahman, 2023; Hatem et al., 2018; Oraee et al., 2019; Oteng et al., 2018)
E5	Increasing reworks	(Oraee et al., 2019; Sawhney & Singhal, 2013; Siddiqui et al., 2019)
E6	Reduced productivity	(Hatem et al., 2018; Matarneh & Hamed, 2017; Siddiqui et al., 2019)
E7	Reduced construction safety.	(Chan, 2014; Matarneh & Hamed, 2017; Siddiqui et al., 2019)
E8	Increasing number of workers on sites	(Chan, 2014; Saka & Chan, 2023; Siddiqui et al., 2019)
E9	Reduced Constructability	(Chan, 2014; Hatem et al., 2018; Samimpey & Saghatforoush, 2024; Siddiqui et al., 2019)
E10	Weakness in information documentation	(Chan, 2014; Matarneh & Hamed, 2017; Siebelink et al., 2020)

Although FCM has previously been applied to risk modelling and critical success factors in ERP implementation (e.g., (Lopez & Salmeron, 2012; Zareravasan & Mansouri, 2015)) and general construction project performance (e.g., (Jadidoleslami, Saghatforoush, Zareravasan, & Mansouri, 2025; Kahvandi, Saghatforoush, Zare Ravasan, & Preece, 2019)), these studies have typically focused on single-layer representations of risks, success factors, or performance drivers within broader project management or technology adoption contexts. To date, no published work has developed a multi-layer FCM that simultaneously captures (i) a comprehensive set of categorized obstacles specific to BIM adoption in the architectural design phase, (ii) their propagated intermediate negative consequences, and (iii) the quantifiable aggregated effects on the classic triple project constraints of time, cost, and quality. The present study addresses this gap by constructing and validating the first such layered FCM model, informed by expert knowledge from a large-scale real-world commercial project, thereby providing a more granular, causal, and decision-oriented framework for understanding and mitigating BIM implementation challenges at the critical early design stage..

As mentioned earlier, this study is to analyze the consequences of the obstacles on BIM application in the architectural design and their effect on time, cost, and quality. In recent years, the obstacles to BIM implementation in the architectural design phase have led to the lack of complete use of all potentials of BIM technology in the architectural design phase. These obstacles may influence each other and intensify each other's effects. Their effect on time, cost and quality is also evident and undeniable. To analyze and evaluate these effects, the next section describes the research method applied.

3. RESEARCH METHODOLOGY

The purpose of this study is to identify the consequences of Obstacles on BIM application in architectural design, as well as their impact on each other and on the project's time, cost, and quality. Considering this, a Fuzzy Cognitive Map (FCM) model is designed, which helps to identify and avoid undesired consequences in construction projects. This model can be used to identify performance and success indicators (Xirogiannis &

To implement such analysis, at first, a casual path from some concept node (C_i) to concept node (C_j), say $C_i \rightsquigarrow C_{k1} \rightsquigarrow \dots \rightsquigarrow C_{kn}$, $C_{kn} \rightsquigarrow C_j$ can be indicated by sequence (i, k_1, \dots, k_n, j) . Then the indirect effect of C_i on C_j is the causality $C_i \rightsquigarrow C_j$ impart to C_j via the path (i, k_1, \dots, k_n, j) . The general effect of C_i on C_j is the compound of all indirect effect causalities $C_i \rightsquigarrow C_j$ (Kosko, 1986). A simple fuzzy causal algebra is created by interpreting the indirect effect operator I as the minimum operator (or t-norm) and the general effect operator T as the maximum operator (or s-norm) on the partially ordered set P of causal values (Pelaez & Bowles, 1996). Formally let \sim be a causal concept space and let $e: \sim \times \sim \rightarrow P$ be a fuzzy causal edge function, and assume that there are m -many causal paths from C_i to C_j : (i, k_1, \dots, k_r, j) for $1 \leq r \leq m$. Then let $I_r(C_i, C_j)$ indicate the indirect effect of concept C_i on concept C_j via the " r "th causal path, and let $T(C_i, C_j)$ represent the general effect of C_i on C_j over all m causal paths. Then:

$$I_r(C_i, C_j) = \min(w(C_{p_r}, C_{p_{r+1}}), \dots, (p_r, p_{r+1}) \rightsquigarrow (i, k_1, \dots, k_r, j)) \quad (1)$$

$$T(C_i, C_j) = \max(I_r(C_i, C_j)), \text{ where } 1 \leq r \leq m \quad (2)$$

Where p and $p+1$ are contiguous left to right path indices (Papageorgiou, 2010).

Dynamic analysis, on the other hand, starts with an extracted model_ as mentioned above_ and an initial state of the corresponding system, which represents weight matrix W and initial vector A_0 , respectively. A_0 depicts the existing states of each concept in the modelled system.

The ultimate goal of the dynamic analysis is estimation of the final state of these concepts under causal and effective relationships of the model. Thus, to reach this goal, an iterative process commences and is used at each step for calculating the new value of concepts as shown in the equation 3 (Groumos, 2010).

$$A_i^t = f \left(\sum_{\substack{j=1 \\ j \neq i}}^n A_j^{t-1} W_{ji} + A_i^{t-1} \right) \quad (3)$$

A_i^t is the value of concept C_i at time t , A_i^{t-1} the value of concept C_i at time $t-1$, A_j^{t-1} the value of concept C_j at time $t-1$, and the weight W_{ji} of the interconnection from concept C_j to concept C_i . The function f is a threshold function and squashes the result in the interval (Glaser, 1978). This value indicates at which level this concept gets activated (Hobbs et al., 2002). The activation level can represent membership in the fuzzy set, describing linguistic measures of relative abundance (e.g., low, average, and high) (Kosko, 1986). Furthermore, the logarithmic sigmoid function is applied here to activate any concept's value, where $\omega > 0$ determines the steepness of the continuous function f as equation 4:

$$f(x) = \frac{1}{1 + e^{-\omega(x)}} \quad (4)$$

3.2 Selecting experts and forming the panel

FCM graphs are built from any data that shows causal relationships or with the support of a single expert or a panel of experts (Rodríguez Repiso, Setchi, & Salmeron, 2007). The output of this technique highly relies on the quality of input data. To improve final graph's reliability and consistency, using a panel of experts is recommended (Yaman & Polat, 2009). A heterogeneous panel is a group of people with the same knowledge but at different social or professional levels. (Zare Ravasan & Mansouri, 2014). Hence, to build and validate the model, a panel of experts is used.

The optimal number of participants depends on the characteristics of research. However, it is recommended that the greater the heterogeneity of the panel is, the fewer the number of participants can be.

Given the heterogeneity of the panel (project managers, employers, designers, consultants, and contractors) and their varied professional backgrounds, we did not aim for a large panel size (see Table 2 for demographics of experts). In addition, the selected experts had participated in different construction projects. This team composition guarantees that the selected participants have a profound knowledge of BIM obstacles and challenges. Moreover, based on the recommendations on the FCM sample size on the heterogeneous panel of experts (Lopez & Salmeron,

2012; E.I. Papageorgiou et al., 2009), the study sample size is 10. The panel size is similar to that of prior FCM studies (Elpiniki I. Papageorgiou, Athanasios Markinos, & Theofanis Gemptos, 2009; Salmeron, 2009, 2010).

Table 2: Demographics of the experts in the panel.

Id	Role	Field	Characteristics
Expert1	Head of the Project management office	Consultant	25 years of experience Post-graduate in the field of construction Having direct cooperation in in the infrastructure project
Expert2	Project manager	Contractor	14 years of experience Undergraduate in the field of construction Having direct cooperation in the infrastructure project
Expert3	Architectural Designer	Consultant	16 years of experience Undergraduate in the field of construction Having direct cooperation in the Commercial projects
Expert4	Technical expert	Contractor	8 years of experience Undergraduate in the field of construction Having direct cooperation in the construction project
Expert5	Architectural Designer	Employer	14 years of experience Undergraduate in the field of construction Having direct cooperation in Design and construction projects
Expert6	Technical expert	Employer	13 years of experience Post-graduate in the field of construction Having direct cooperation in the construction project
Expert7	Head of Design Team	Consultant	25 years of experience Post-graduate in the field of construction Having direct cooperation in the Commercial projects
Expert8	Technical expert	Contractor	16 years of experience Undergraduate in the field of construction Having direct cooperation in the construction project
Expert9	Executive Supervisor	Contractor	19 years of experience Undergraduate in the field of construction Having direct cooperation in the infrastructure project
Expert10	Architectural Designer	Consultant	18 years of experience Post-graduate in the field of construction Having direct cooperation in the Design and construction project

In order to grasp a full view of BIM obstacles, people with planning, design, procurement and site operations experience are required, as these are the main underlying concepts of BIM definition (Disney, Roupé, Johansson, & Domenico Leto, 2024; Fadeyi, 2017). Throughout the panelling process, the field expertise was targeted (e.g., design, and construction) rather than affiliated bodies (e.g., employer, consultant, and contractor). Accordingly, four experts in design domain are included in this study (Experts #3, #5, #7, #10), and three experts with construction experience (Experts #4, #6, #8). Besides, two project managers (Experts #1, #2) and one Executive Supervisor (Expert#7) for the sake of having multi-disciplinary experience in the panel are also included (to have views on other areas than design and construction, such as planning and procurement). These multi-disciplinary experts are highly experienced in the field, each of which have at least 20-years of domain knowledge. Above all, experts with both academic and practice knowledge and experience are also included, which facilitated explaining the method and weighting procedure.

The project studied in this research belongs to one of the largest commercial-administrative complexes in the Middle East with a specific area of about 740,000 square meters in the west of Tehran, the capital of Iran. Construction of the project began in 2016 and most of it were operational by 2024. The project consists of several main sections, including a tower, a set of commercial, office, retail and store spaces, an amphitheatre hall, a cultural sports complex, and the required parking lots of about 70 floors. Due to the scale of the project, many contractors and subcontractors are working on it. During the construction phase, due to conflicts between contractor and

designer, a large part of the project was out of order, or some duplication occurred. The stakeholders' targeted study include two of the top ten experts on the home page (e.g., Expert No. 5 and Expert No. 9).

3.3 Creating the FCM model

As the first step to create the FCM model, the BIM obstacles are identified and conceptualized along with their consequences. An FCM model is specifically built for predicting the joint influences of obstacles by categorizing them as organizational, technical, skills, and environmental obstacles.

Then, the conceptual validity of the created model is assessed. We thus sought to corroborate whether the concepts (obstacles, consequences, failure modes) underlying the conceptual framework are correct and enough to model the impact of obstacles on the outcomes of projects.

In doing so, first in the literature review, every relevant concept into the model are identified, following the idea of theoretical saturation (Breckenridge & Jones, 2009), so that at the end of the review, we were not able to find any new concept to add the model. This process assures the content validity of the concepts. Second, all panel experts are asked the following question: "Is this research looking at the study of BIM obstacles from an appropriate perspective, and do you think we have a complete list of concepts?" The whole set of panel experts answered affirmatively. In addition, they approved the identified obstacles and consequences impact on the outcomes of construction projects.

Through the process, a list of 23 obstacles are identified and validated as the model's first layer, 10 obstacles' consequences as the second layer; and three project failure modes (e.g., time, cost, and quality) as the third layer (see Figure 2).

Values in the Appendices II, III, and IV represent the causes and effects in the FCM model. Regarding the density of model, the final FCM model contains 23 nodes in the first layer with 45 arcs/arrows (see Appendix II), 10 nodes with 40 arcs in the second layer (see Appendix III) and three nodes with 15 arcs in the third layer (see Appendix IV), making a total 36 nodes interconnected through 100 arcs. It shows that the BIM obstacles and project outcomes are highly interrelated, which indicates the complexity of the model. Regarding a large number of nodes and underlying interconnections, only a partial representation of the model is provided in Figure 2.

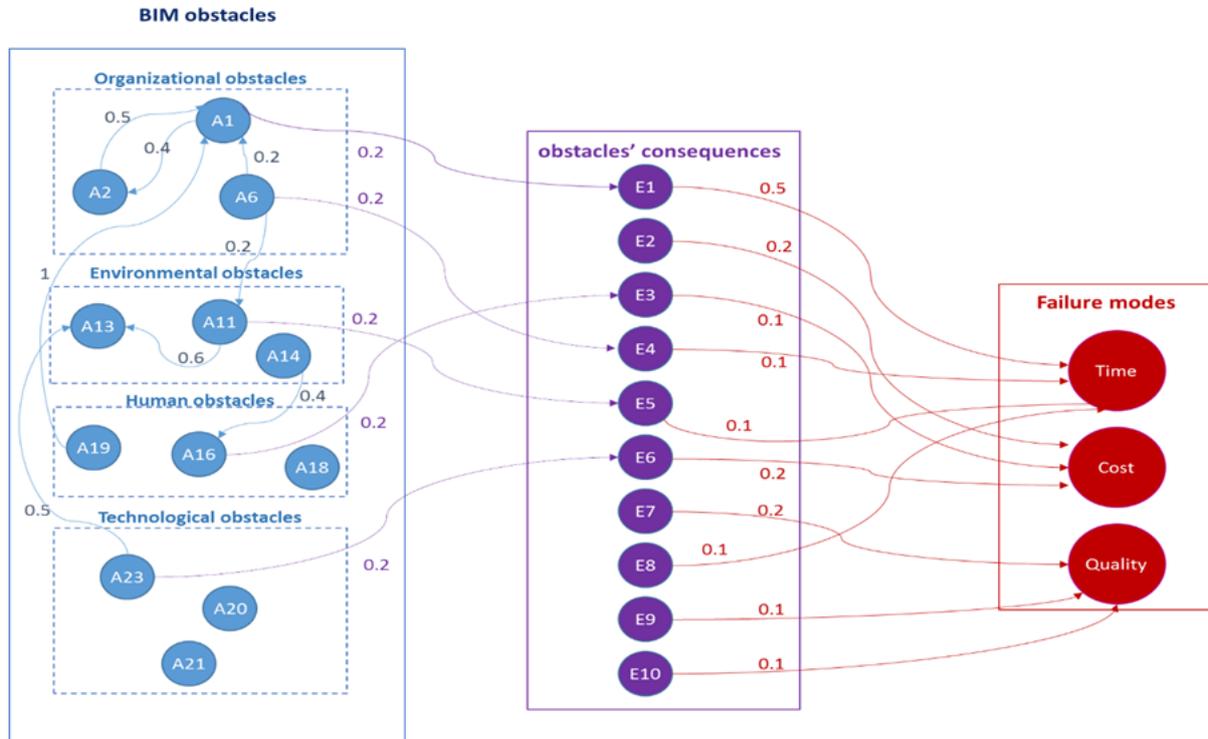


Figure 2: BIM obstacles, consequences, and project failure modes.

To model the interdependencies, at first, all panel experts are asked to represent the existed interactions: a) among BIM obstacles, and b) from obstacles to the consequences, and then c) from the consequences to project failure modes.

Each panel expert is separately asked to describe the degree of interactions utilizing linguistic variables on a 10-point scale from strongly low to strongly high. In cases where the assigned values are far from each other, they are asked to refine their judgment. Nevertheless, where consensus is not achieved, they are asked to explain why such values were assigned. Thus, one of the judgments is picked out according to their explanations. This procedure assures that the weighting outcome is not biased with a single point of view (i.e., design, construction, or others), and all parties have jointly reached a consensus over the outcome. This approach has been used as a method to reach consensus in prior research (Kahvandi et al., 2019; Moalagh & Ravasan, 2013).

In order to get the experimental validity of the model, feedbacks of expert #1 and expert #7 whom were involved in our real case are used. Dynamic analysis is performed in the Section 4.2. The simulation of scenarios demonstrates the applicability and usability of the proposed FCM model. Expert #1 and expert #7 corroborated that the findings achieved in the real project and simulation results (scenario 5) are similar in terms of the obstacles' consequences and project time, cost, and quality.

Therefore, the FCM's forecasts are quite accurate. Finally, the operational validity of the model are verified.

To ensure full replicability of the results, the complete weighted adjacency matrices are provided in Appendices II–IV:

- Appendix II contains all causal relationships among the 23 BIM obstacles (A1–A23),
- Appendix III presents the relationships from obstacles to the 10 intermediate consequences (E1–E10), and
- Appendix IV shows the relationships from consequences to time, cost, and quality.

The initial state vectors for the five scenarios are listed in Table 4. The dynamic analysis employs the standard FCM iterative updating rule (Equation 3) with the logarithmic sigmoid squashing function (Equation 4, $\lambda = 1$). All computations were implemented in Python using standard matrix operations; interested readers can reproduce the equilibrium states by initializing the concept vector with the provided values, applying the weight matrices, and iterating until convergence (typically < 20–30 steps for this model size).

4. FINDINGS AND DISCUSSION

There are two types of analyses in the FCM method. The static analysis depicts the overall effects of each concept on output ones; and dynamic analysis acts as an estimator of the final state of the system. Moreover, it allows investigating "what-if" scenarios by performing simulations of a given model from different initial state vectors, which is provided in this section. The Python programming language is used to implement the algorithm and its analyses.

4.1 Static analysis

The proposed FCM model represents existing static connections from obstacles to project failure modes. Figure 2 depicts the partial graphical representation of the model. To make the model's representation easier and link it with the dynamic analysis of the proposed FCM (explained further ahead in the text the obstacles grouped in organizational, human, technological, and environmental categories are presented.

The Figure 2 is a partial representation because it does not include all the existing interactions. Nevertheless, it represents the following links:

Direct relationships between the obstacles and within the categories (layer 1 in the Figure 2, also see Appendix II).

Direct links from obstacles to ten obstacles' consequences (layer 2 in the Figure 2, also see Appendix III).

Direct relations from obstacles' consequences to the three project failure modes (layer 3 in the Figure 2, also see Appendix IV).

The indirect links also exist in the model, even though they are not directly observable from the Figure. This can be represented by the multiple connections between the model concepts. This is logical since when one obstacle

arises; it may affect other obstacles. For instance, there is no direct link between A1 and A8. However, there is an indirect link between A1 and A8 through A6, since A1 impacts A6 and then A6 links to A8.

It should be noted that all the relations incorporated in the model are positive, meaning that changes in the level of the factors provoke changes in their effect factors in the same direction. Therefore, an increase in the level of one obstacle makes the project failure more likely.

Based on the observed interactions between BIM obstacles (A_i), obstacles' consequences (E_i), and project failure modes (F_i) (see Appendices II, III and IV), the path effect from BIM obstacles to obstacles' consequences ($A_i \sim E_j$) and from there to project failure modes ($E_i \sim F_j$) can be calculated (using equations 1-4), which represent our static analysis. The results of this static analysis are presented below.

The initial result taken static analysis is the indirect effects of obstacles on obstacles' consequences (see Table 3). The causal effects amongst these concepts are drawn using the maximum - minimums analysis (equations 1 and 2); whereas all these obstacles are considered as input and output concepts, simultaneously. Based on achieved results of static analysis, the following interpretations are provided.

Table 3: Indirect effects (based on FCM Max-Mins relations).

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Average* (indirect effects)	Average** (initial effects)	FCM augmentation***
A1	0.2	0.2	0.2	0.2	0	0.2	0	0.1	0.1	0.1	0.13	0.03	0.10
A2	0.2	0.2	0.1	0.2	0	0.1	0	0	0	0	0.08	0.06	0.02
A3	0.1	0	0	0.2	0	0.2	0	0	0	0.2	0.07	0.05	0.02
A4	0	0	0	0.2	0	0	0	0	0	0	0.02	0.02	0.00
A5	0	0	0	0	0	0.2	0	0	0	0	0.02	0.02	0.00
A6	0.2	0	0.1	0.2	0.2	0.4	0.2	0	0	0	0.13	0.06	0.07
A7	0.2	0	0.2	0	0	0.2	0	0.2	0	0	0.08	0.02	0.06
A8	0	0	0	0.2	0	0.4	0	0	0.2	0.2	0.1	0	0.10
A9	0	0.4	0.2	0	0	0	0	0	0.2	0.2	0.1	0.1	0.00
A10	0	0	0	0	0.2	0.2	0.2	0	0	0	0.06	0.04	0.02
A11	0.2	0	0.2	0.2	0.2	0.2	0	0.2	0.2	0	0.14	0.04	0.10
A12	0.2	0	0	0.2	0	0.2	0	0	0	0.2	0.08	0.04	0.04
A13	0.2	0	0.2	0.2	0	0	0	0.2	0	0	0.08	0.08	0.00
A14	0.2	0	0.2	0.2	0	0.2	0	0	0	0.2	0.1	0.02	0.08
A15	0	0	0	0.2	0	0.1	0	0	0	0	0.03	0.02	0.01
A16	0.2	0.2	0.2	0.4	0	0.2	0	0	0	0	0.12	0.06	0.06
A17	0	0	0	0.2	0	0	0	0	0.2	0	0.04	0.04	0.00
A18	0.1	0	0.1	0.1	0	0	0	0.1	0	0	0.04	0	0.04
A19	0.2	0	0.1	0	0	0.2	0	0	0	0	0.05	0.02	0.03
A20	0	0	0	0	0	0.2	0	0.2	0	0	0.04	0.02	0.02
A21	0.2	0	0.2	0.2	0	0	0	0.2	0.2	0	0.1	0.02	0.08
A22	0.2	0	0.1	0.4	0	0.1	0	0.2	0	0	0.1	0.05	0.05
A23	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0.14	0.08	0.12

*Average based on indirect effects (based on FCM Max of Mins relations)

**Average based on initial effects (direct relations, Appendix II)

***FCM augmentation = Average (indirect effects) – Average (Initial effects)

According to the average values (initial effects) provided in the Table 4, A9 with 0.10 is known as the obstacle with the most direct impact, followed by A13 and A23 with 0.08 in the next rank of direct effect. Among them, A23 is in a higher rank in term of indirect effect. Also, in FCM augmentation relationships, the highest values are related to obstacles A11, A8, A1, A21 (0.1 – 0.12). It means that these obstacles have the most effect on the

relationship network of the FCM model in this study. The important point is that the obstacles mentioned are among the main obstacles that not only affect the success or failure of the project, but also influence other obstacles and intensify them. These obstacles should be seriously considered in the field of BIM obstacles.

Table 4: Simulation results of the proposed scenarios.

	Initial State Scenario#1: Organizational	Initial State Scenario#2: Environmental	Initial State Scenario#3: Human	Initial State Scenario#4: Technological	Initial State Scenario#5: our case
A1	1	0	0	0	0.00
A2	1	0	0	0	0.30
A3	1	0	0	0	0.20
A4	1	0	0	0	0.30
A5	1	0	0	0	0.00
A6	1	0	0	0	0.30
A7	1	0	0	0	0.00
A8	1	0	0	0	0.00
A9	0	1	0	0	0.20
A10	0	1	0	0	0.30
A11	0	1	0	0	0.10
A12	0	1	0	0	0.30
A13	0	1	0	0	0.20
A14	0	1	0	0	0.30
A15	0	0	1	0	0.40
A16	0	0	1	0	0.25
A17	0	0	1	0	0.20
A18	0	0	1	0	0.50
A19	0	0	1	0	0.10
A20	0	0	0	1	0.10
A21	0	0	0	1	0.05
A22	0	0	0	1	0.10
A23	0	0	0	1	0.00
	Final State Scenario#1: Organizational	Final State Scenario#2: Environmental	Final State Scenario#3: Human	Final State Scenario#4: Technological	Final State Scenario#5: our case
E1	0.60	0.58	0.54	0.00	0.55
E2	0.54	0.58	0.00	0.00	0.53
E3	0.52	0.58	0.54	0.00	0.53
E4	0.65	0.58	0.58	0.58	0.59
E5	0.00	0.58	0.00	0.00	0.52
E6	0.65	0.00	0.58	0.60	0.55
E7	0.00	0.54	0.00	0.00	0.51
E8	0.54	0.54	0.00	0.00	0.51
E9	0.00	0.58	0.54	0.54	0.52
E10	0.00	0.58	0.00	0.00	0.52
Time	0.58	0.63	0.57	0.51	0.63
Cost	0.56	0.65	0.64	0.63	0.65
Quality	0.54	0.58	0.54	0.52	0.58



4.2 Dynamic analysis

The FCM method provides excellent mechanisms to develop forecasting exercises. Specifically, the results indicate the level of influence of a set of obstacles on the outcomes of projects that enables us to develop “what-if” analysis, supporting critical decision-making (E.I. Papageorgiou, 2011). Thus, practitioners can identify the possible consequences under each scenario. Moreover, they can understand the necessary changes required for their construction projects.

Dynamic analysis of FCM requires definition of an initial scenario, which represents a proposed initial situation to assess. Here, five scenarios are applied by activating a set of specific obstacles in each run. Indeed, scenarios describe events and situations that are likely to happen in practice. Thus, we wanted to quantify, in relative terms, the joint level of influence of obstacles in each category on the project outcome. For instance, the first scenario is related to the condition in which only organizational obstacles contribute to the model, while other obstacles are deactivated. Likewise, scenarios 2 to 4 are respectively related to environmental, human and technological sources of obstacles. Any other desired set of obstacles can also be activated to help further interpretations. Finally, scenario 5 runs using the case data (through expert #1 and expert #7). Table 4 illustrates the initial condition of each scenario with its value in the equilibrium point. Subsequently, the initial state of each scenario are being updated, as shown in the Equations 3 and 4, as an activation function until reaching such a steady-state point, in which there are no further accessible updates. It means that the new calculated vector at a step such as k has either no or negligible difference with its previous vector ($k-1$).

According to Table 4, it seems that except obstacles A1, A5, A7, A8, and A23, the other obstacles in all 4 scenarios have a relatively close effect in the real case. To start, in scenarios related to human factors that are from A15 to A19 and technical factors that are from A20 to A23, two obstacles A18 (No guarantee for smaller projects to use BIM) and A15 (Lack of compatible data standards and formats/ incompatibility with common standards in this study) had the most influence on the architectural design phase. The use of BIM in projects requires using a standard approach and developing the requirements and frameworks based on it. The existing experiences show that one of the most important reasons for unsuccessful implementation of BIM is lack of the required standards and formats. Localization and development of the required frameworks and standards for BIM at the national, organizational, and project levels requires the presence of experienced experts in the field of science and implementation (Babatunde et al., 2020). Developing a database for building materials, products, and systems with related technical specifications as a basic BIM database, creating a library of objects for building elements and components with participation of manufacturers compatible with specialized rules and standards and connected to the database, developing relevant software and plug-ins are among the requirements that should be considered in the development of standards, and should be considered as the basis for architectural design to increase constructability (Jadidoleslami & Saghatforoush, 2018; Jadidoleslami et al., 2018; Saghatforoush et al., 2023; Samimpey & Saghatforoush, 2024). Regarding the lack of guarantees for the use of BIM in smaller projects, many individuals doubt the benefits and value of using BIM (Farouk et al., 2023; M. Hosseini, Namzadi, Rameezdeen, Banihashemi, & Chileshe, 2016). Some BIM processes are not yet defined, partly because it is a new approach and partly because the efforts depend on all the stakeholders' work with each other. To achieve the maximum potential of the team, all project stakeholders should discuss the required building data and its effect on the project life cycle; but this may not always be possible in smaller projects. In other words, BIM implementation on a small scale has been stopped due to lack of experts, time and cost for training BIM. However, it can be said that in smaller projects, there is no room for maneuvering because of less budget; but making mistakes in the architectural design phase is more evident in larger projects.

In scenario 1, the obstacles intensify negative impact on all three factors of time, cost, and quality. Its most significant impact on time (0.58) is evident. Meanwhile, in scenario 1, the organizational issues are more influenced by E4 (Lack of teamwork mentality) and E6 (Reduced productivity). BIM is a useful tool for project managers to control the project and increase its productivity and decrease its wastes by displaying a 3D image of project designs, controlling their interferences, and providing an implementation view of the schedule as well as an accurate estimation of project costs (Siddiqui et al., 2019). The criteria of optimal productivity is usually known as indicator of return on investment in using BIM, and is one of the criteria related to the delivery process. Stability and even lower productivity rates over the last few decades (even in developed countries) are a consequence of this backwardness in the construction industry. In fact, BIM is a step toward more automation ideas in this industry

(Balaguer & Abderrahim, 2008; Cassandro, Mirarchi, Gholamzadehmir, & Pavan, 2024). Lack of this approach in projects will reduce the expected productivity and output.

In scenario 2 that is about environmental factors, the most negative effects are observed in relation to time (0.63). While environmental issues will be influenced by E6 (Reduced productivity) less than others, in other cases the similar and close effects are observed. In scenarios 3 and 4 related to human and technical issues, the negative effects regarding costs are more evident than in other cases. However, it is interesting that these two scenarios are not influenced by most of the existing Es. In both scenarios, the most impact is related to the effects of E4 (Lack of teamwork mentality). However, in scenario 3, E6 (Reduced productivity) is equally effective.

In scenario 5, which is related to case studies, this study is influenced mainly by E4 (Lack of teamwork mentality). Moreover, the obstacles intensified the negative effects on all three areas of time, cost, and quality. Its greatest effect is on cost (0.65). However, in terms of time, these negative effects are observable with little difference. Perhaps the reason for this issue is the necessity of institutionalization of teamwork and teamwork mentality in the BIM approach, the lack of which has direct and indirect negative effects on increasing cost and time of project completion. Lack of collaboration between different working groups will lead to poor transfer of information between different phases of the project and duplications and increased changes; and this is inevitable. Lack of mutual trust between key project stakeholders in management and financial issues and lack of proper definition of teamwork culture among key project stakeholders reduces the spirit of teamwork in the architectural design phase (Pishdad-Bozorgi, 2017).

Overall, one of the interesting findings is the most negative effect of E4 (Lack of teamwork mentality) in all scenarios. The BIM process is pervasive, and its implementation in large-scale projects is a very difficult task. It shows its real value in integrating and connecting the activities. Therefore, working as a team on a project from the same architectural design phase to accelerate the work is very important. Even defining BIM as a culture for a team's success is one of the most important steps of BIM implementation in an organization, company, project, or a design or implementation team. It is vital to develop a collective thinking mentality for the project team that believes in BIM as an organizational and work culture, and takes advantage of it (Alankarage, Chileshe, Samaraweera, Rameezdeen, & Edwards, 2024; Oteng et al., 2018). The more this culture expands, the more successful the results of BIM will be.

5. CONCLUSION

The aim of this study was to identify the consequences of obstacles on BIM application in the architectural design phase and evaluate the effect of these obstacles on each other and on three factors of time, cost, and quality. In this research, through a case study and focus on the obstacles for BIM implementation, the factors affecting time, cost, and quality are modeled. The FCM approach is used to evaluate and develop this model. According to the obtained results, skill, environmental, technological, and organizational factors were more effective than other factors. This indicates the need for studying and reviewing the current processes for BIM implementation in the architectural design phase. Examining the scenarios presented in the analysis section, it can be concluded that factors 'No guarantee for smaller projects to use BIM' and 'Lack of compatible data standards and formats with common standards' had the most influence compared to other.

Both these factors were in the category of human factors. So perhaps by focusing more on human factors that emphasize team building and promoting culture for teamwork, the occurrence of these obstacles in projects can be prevented. Moreover, skill, environmental, technological, and organizational factors have been influenced mostly by 'Lack of teamwork mentality'. On the other hand, the results show that the effects on time, cost, and quality in environmental factors are more than other factors. The willingness of individuals to teamwork in the project increases by decreasing self-centeredness, increasing social tolerance, increasing the legitimacy of people, increasing trust between stakeholders, and decreasing secrecy.

All these factors depend on the growth and promotion of culture and change of the traditional views. Therefore, by focusing on resolving these cultural obstacles rooted in traditional thinking and resistance to change and training and building trust, the ground to reduce these obstacles is prepared.

It is highly recommended that future studies analyze solutions to resolve these obstacles by collecting experts' suggestions in cases where the use of BIM in the design phase was accompanied by fewer construction problems. Rooting and analyzing each of the factors emphasized in this research project can help resolve these obstacles.

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- **Ahad Zareravasan:** methodology, validation, formal analysis,
- **Samereh Jadidoleslami:** conceptualization, methodology, validation, formal analysis, writing original draft, visualization, project administration, Writing (review and editing),
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REFERENCES

- Al-Zwainy, F. M., Mohammed, I. A., & Al-Shaikhli, K. A. (2017). Diagnostic and assessment benefits and barriers of BIM in construction project management. *Civil Engineering Journal*, 3(1), 63-77.
- Alankarage, S., Chileshe, N., Samaraweera, A., Rameezdeen, R., & Edwards, D. J. (2024). Diagnosing Organizational BIM Culture: A Qualitative Case Study Using Schein's Model. *Journal of management in engineering*, 40(3), 05024005.
- Allban, A. S. S. (2024). Implementing LEAN-BIM in construction management in Iraq: Insights and Future Opportunities.
- Ariono, B., Wasesa, M., & Dhewanto, W. (2022). The Drivers, Barriers, and Enablers of Building Information Modeling (BIM) Innovation in Developing Countries: Insights from Systematic Literature Review and Comparative Analysis. *Buildings*, 12(11), 1912.
- Babatunde, S. O., Udeaja, C., & Adekunle, A. O. (2020). Barriers to BIM implementation and ways forward to improve its adoption in the Nigerian AEC firms. *International Journal of Building Pathology and Adaptation*.
- Balaguer, C., & Abderrahim, M. (2008). Robotics and automation in construction: BoD–Books on Demand.
- Biloslavo, R., & Dolinsek, S. (2008). Scenario planning for climate strategies development by integrating group Delphi, AHP and dynamic fuzzy cognitive maps. Paper presented at the PICMET'08-2008 Portland International Conference on Management of Engineering & Technology.
- Bosch-Sijtsema, P., Isaksson, A., Lennartsson, M., & Linderoth, H. C. (2017). Barriers and facilitators for BIM use among Swedish medium-sized contractors—"We wait until someone tells us to use it". *Visualization in engineering*, 5(1), 3.
- Brahmi, B. F., & Sassi-Boudemagh, S. (2024). BIM IMPLEMENTATION FOR HERITAGE RENOVATION THROUGHOUT PROJECT LIFECYCLE: CURRENT USE, BENEFITS, AND BARRIERS. *Architecture and Engineering*, 9(3), 15-26.
- Breckenridge, J., & Jones, D. (2009). Demystifying Theoretical Sampling in Grounded Theory Research, *Grounded Theory Review*. 8, 113-126.
- Bueno, S., & Salmeron, J. L. (2008). Fuzzy modeling enterprise resource planning tool selection. *Computer Standards & Interfaces*, 30(3), 137-147.
- Butt, A., Naaranoja, M., & Savolainen, J. (2016). Project change stakeholder communication. *International Journal of Project Management*, 34(8), 1579-1595.



- Cassandro, J., Mirarchi, C., Gholamzadehmir, M., & Pavan, A. (2024). Advancements and prospects in building information modeling (BIM) for construction: a review. *Engineering, Construction and Architectural Management*.
- Chan, C. T. (2014). Barriers of implementing BIM in construction industry from the designers' perspective: A Hong Kong experience. *Journal of System and Management Sciences*, 4(2), 24-40.
- Cho, H., Lee, K. H., Lee, S. H., Lee, T., Cho, H. J., Kim, S. H., & Nam, S. H. (2011). Introduction of Construction management integrated system using BIM in the Honam High-speed railway lot No. 4-2. *Proceedings of the 28th ISARC*, Seoul, Korea.
- Christoforou, A., & Andreou, A. (2016). A Framework for Static and Dynamic Analysis of Multi-Layer Fuzzy Cognitive Maps. *Neurocomputing*, 232. doi:10.1016/j.neucom.2016.09.115
- Dave, B., Buda, A., Nurminen, A., & Främling, K. (2018). A framework for integrating BIM and IoT through open standards. *Automation in Construction*, 95, 35-45.
- Dave, B., Kubler, S., Främling, K., & Koskela, L. (2016). Opportunities for enhanced lean construction management using Internet of Things standards. *Automation in Construction*, 61, 86-97.
- Demeke Wasse, A., & Dai, K. (2024). Building Information Modeling Adoption, Implementation, and Challenges in the Ethiopian Construction Industry. *Journal of Architectural Engineering*, 30(3), 04024018.
- Disney, O., Roupé, M., Johansson, M., & Domenico Leto, A. (2024). Embracing BIM in its totality: a Total BIM case study. *Smart and Sustainable Built Environment*, 13(3), 512-531.
- Eastman, C. M., Eastman, C., Teicholz, P., & Sacks, R. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*: John Wiley & Sons.
- El Hajj, C., Martínez Montes, G., & Jawad, D. (2023). An overview of BIM adoption barriers in the Middle East and North Africa developing countries. *Engineering, Construction and Architectural Management*, 30(2), 889-913.
- Enshassi, A., & AbuHamra, L. A. (2017). Challenges to the Utilization of BIM in the Palestinian Construction Industry. Paper presented at the 34th International Symposium on Automation and Robotics in Construction (ISARC2017). <http://hdl.handle.net/20.500.12358/26575>
- Eze, E. C., Aghimien, D. O., Aigbavboa, C. O., & Sofolahan, O. (2024). Building information modelling adoption for construction waste reduction in the construction industry of a developing country. *Engineering, Construction and Architectural Management*, 31(6), 2205-2223.
- Fadeyi, M. O. (2017). The role of building information modeling (BIM) in delivering the sustainable building value. *International Journal of Sustainable Built Environment*, 6(2), 711-722.
- Farouk, A. M., Zulkhisam, A. Z., Lee, Y. S., Rajabi, M. S., & Rahman, R. A. (2023). Factors, challenges and strategies of trust in BIM-Based construction projects: A case study in Malaysia. *Infrastructures*, 8(1), 13.
- Glaser, B. (1978). *Theoretical sensitivity: Advances in the methodology of grounded theory*. Sociology Press.
- Glykas, M. (2010). *Fuzzy cognitive maps: Advances in theory, methodologies, tools and applications* (Vol. 247): Springer.
- Groumpos, P. P. (2010). *Fuzzy Cognitive Maps: Basic Theories and Their Application to Complex Systems*. *Fuzzy Cognitive Maps; Advances in Theory, Methodologies, Tools and Applications*, Berlin: Springer, 1–22.
- Hamidi Monozam, N., Monozam, H. H., Hosseini, M. R., & Zaeri, F. (2016). Barriers to adopting building information modelling (BIM) within South Australian small and medium sized enterprises. Paper presented at the Fifth International Scientific Conference on Project Management in the Baltic Countries, University of Latvia.
- Hamma-adama, M., Kouider, T., & Salman, H. (2020). Analysis of barriers and drivers for BIM adoption. *International journal of BIM and engineering science*, 3(1). Retrieved from <http://bimarabia.com/IJBES/>

- Hatem, W. A., Abd, A. M., & Abbas, N. N. (2018). Barriers of adoption Building Information Modeling (BIM) in construction projects of Iraq. *Engineering Journal*, 22(2), 59-81.
- Hobbs, B. F., Ludsin, S. A., Knight, R. L., Ryan, P. A., Biberhofer, J., & Ciborowski, J. J. (2002). Fuzzy cognitive mapping as a tool to define management objectives for complex ecosystems. *Ecological Applications*, Vol. 12 No. 5, 1548–1565.
- Hosseini, M., Namzadi, M. O., Rameezdeen, R., Banihashemi, S., & Chileshe, N. (2016). Barriers to BIM adoption: Perceptions from Australian small and medium-sized enterprises (SMEs). Paper presented at the AUBEA 2016: Proceedings of the 40th Australasian Universities Building Education Association Annual Conference.
- Hosseini, M. R., Azari, E., Tivendale, L., Banihashemi, S., & Chileshe, N. (2016). Building Information Modeling (BIM) in Iran: an exploratory study. *Journal of engineering, project, and production management*, 6(2), 78-89.
- Hosseini, M. R., Azari, E., Tivendale, L., & Chileshe, N. (2015). Barriers to adoption of building information modeling (BIM) in Iran: Preliminary results. Paper presented at the proceedings of the The 6th International Conference on Engineering, Project, and Production Management (EPPM2015).
- Jadidoleslami, s., Azizi, M., Sobhiyah, M., & Zareravasan, A. (2025). A CROSS-IMPACT ANALYSIS OF DIGITAL TRANSFORMATION FACTORS IN CONSTRUCTION FIRMS: A MICMAC APPROACH. *Journal of Construction Engr. & Management*. doi:10.1061/JCEMD4/COENG-16775
- Jadidoleslami, S., & Saghatforoush, E. (2018). Parallel impact of IPD and BIM approaches on facilitating constructability implementation.
- Jadidoleslami, S., & Saghatforoush, E. (2026). Unveiling Diverse AI Applications in BIM: A Quantitative Mapping of Techniques for 10 Dimensions. *ARCHITECTURAL ENGINEERING AND DESIGN MANAGEMENT*. doi:10.1080/17452007.2025.2579741
- Jadidoleslami, S., Saghatforoush, E., & Zare Ravasan, A. (2018). Constructability obstacles: an exploratory factor analysis approach. *International Journal of Construction Management*, 21(3), 312-325.
- Jadidoleslami, S., Saghatforoush, E., Zareravasan, A., & Mansouri, T. (2025). Constructability obstacles: an FCM-based dynamic modelling Infrastructure Asset Management, 1-24. doi:https://doi.org/10.1680/jinam.23.00020
- Jose L. Salmerona, Mansouri, T., Mohammad Reza Sadeghi Moghadam, & Amirhosein Mardani. (2019). Learning Fuzzy Cognitive Maps with modified asexual reproduction optimisation algorithm. *Knowledge-Based Systems*, 163, 723-735.
- Kahvandi, Z., ., Saghatforoush, E., Zare Ravasan, A., & Preece, C. (2019). Integrated Project Delivery Implementation Challenges in the Construction Industry. *Civil Engineering Journal*.
- Kekana, T., Aigbavboa, C., & Thwala, W. (2014). Building information modelling (BIM): Barriers in adoption and implementation strategies in the South Africa construction industry. Paper presented at the International Conference on Emerging Trends in Computer and Image Processing, Pattaya, Thailand.
- Kineber, A. F., Othman, I., Famakin, I. O., Oke, A. E., Hamed, M. M., & Olayemi, T. M. (2023). Challenges to the implementation of building information modeling (BIM) for sustainable construction projects. *Applied Sciences*, 13(6), 3426.
- Kleijnen, J. P. C. (1995). Verification and validation of simulation models. *European Journal of Operational Research*, 82(1), 145-162. doi:https://doi.org/10.1016/0377-2217(94)00016-6
- Kosko, B. (1986). Fuzzy Cognitive Maps. *International Journal of Man-Machine Studies*, 65–75.
- Krygiel, E., & Nies, B. (2008). *Green BIM: successful sustainable design with building information modeling*: John Wiley & Sons.
- Lahdou, R., & Zetterman, D. (2011). BIM for Project Managers How project managers can utilize BIM in construction projects.

- Latiffi, A. A., Mohd, S., Kasim, N., & Fathi, M. S. (2013). Building information modeling (BIM) application in Malaysian construction industry. *International Journal of Construction Engineering and Management*, 2(4A), 1-6.
- Liu, S., Xie, B., Tivendal, L., & Liu, C. (2015). Critical barriers to BIM implementation in the AEC industry. *International Journal of Marketing Studies*, 7(6), 162.
- Lopez, C., & Salmeron, J. L. (2012). Dynamic risks modelling in ERP maintenance projects with FCM. *Information Sciences*. doi:<https://doi.org/10.1016/j.ins.2012.05.026>.
- Manzoor, B., Othman, I., Gardezi, S. S. S., Altan, H., & Abdalla, S. B. (2021). BIM-based research framework for sustainable building projects: a strategy for mitigating BIM implementation barriers. *Applied Sciences*, 11(12), 5397.
- Matarneh, R., & Hamed, S. (2017). Barriers to the adoption of building information modeling in the Jordanian building industry. *Open journal of civil engineering*, 7(3), 325-335.
- Mishra, A., Hasan, A., & Jha, K. N. (2024). A Holistic Evaluation of BIM Implementation Barriers in the Indian Construction Industry: Pre-and Post-Adoption Perspectives. *International Journal of Construction Education and Research*, 1-23.
- Moalagh, M., & Ravasan, A. Z. (2013). Developing a practical framework for assessing ERP post-implementation success using fuzzy analytic network process. *International Journal of Production Research*, 51(4), 1236-1257. doi:[10.1080/00207543.2012.698318](https://doi.org/10.1080/00207543.2012.698318)
- Nsimbe, A., & Di, J. (2024). The Impact of Building Information Modeling Technology on Cost Management of Civil Engineering Projects: A Case Study of the Mombasa Port Area Development Project. *Buildings*, 14(4), 1175.
- Oraee, M., Hosseini, M. R., Edwards, D. J., Li, H., Papadonikolaki, E., & Cao, D. (2019). Collaboration barriers in BIM-based construction networks: A conceptual model. *International Journal of Project Management*, 37(6), 839-854.
- Oral, M., & Kettani, O. (1993). The facets of the modeling and validation process in operations research. *European Journal of Operational Research*, 66(2), 216-234. doi:[https://doi.org/10.1016/0377-2217\(93\)90314-D](https://doi.org/10.1016/0377-2217(93)90314-D)
- Oteng, D., Ansah, M. K., Kissi, E., & Eshun, B. T. B. (2018). Barriers to the Adoption of Building Information Modeling in Developing Countries: The Case of Ghana. Paper presented at the 1st International Conference on Construction Futures.
- Papageorgiou, E. I. (2010). A Novel Approach on Constructed Dynamic Fuzzy Cognitive Maps Using Fuzzified Decision Trees and Knowledge Extraction Techniques Fuzzy Cognitive Maps Advances in Theory. Methodologies, Berlin: Springer, 44–72.
- Papageorgiou, E. I. (2011). A new methodology for decisions in medical informatics using fuzzy cognitive maps based on fuzzy rule-extraction techniques. *Applied Soft Computing*, Vol. 11 No. 1, 500–513.
- Papageorgiou, E. I. (2011). Review study on fuzzy cognitive maps and their applications during the last decade. Paper presented at the 2011 IEEE international conference on fuzzy systems (FUZZ-IEEE 2011).
- Papageorgiou, E. I., Markinos, A., & Gemptos, T. (2009). Application of fuzzy cognitive maps for cotton yield management in precision farming. *Expert Systems with Applications*, Vol. 36 No. 10, 12399–12413.
- Papageorgiou, E. I., Markinos, A., & Gemptos, T. (2009). Application of fuzzy cognitive maps for cotton yield management in precision farming. *Expert Syst. Appl.*, 36(10), 12399–12413. doi:[10.1016/j.eswa.2009.04.046](https://doi.org/10.1016/j.eswa.2009.04.046)
- Parsamehr, M., Perera, U. S., Dodanwala, T. C., Perera, P., & Ruparathna, R. (2023). A review of construction management challenges and BIM-based solutions: perspectives from the schedule, cost, quality, and safety management. *Asian Journal of Civil Engineering*, 24(1), 353-389.

- Pei Tang, Amlan Mukherjee, & Onder, N. (2010). Strategy optimization and generation for construction project management using an interactive simulation. *Proceedings of the 2010 Winter Simulation Conference*. doi: 10.1109/WSC.2010.5679002
- Pelaez, C. E., & Bowles, J. B. (1996). Using fuzzy cognitive maps as a system model for failure modes and effects analysis. *Information Science*, 339–346.
- Pishdad-Bozorgi, P. (2017). Case studies on the role of integrated project delivery (IPD) approach on the establishment and promotion of trust. *International Journal of Construction Education and Research*, 13(2), 102-124.
- Rodríguez Repiso, L., Setchi, R., & Salmeron, J. (2007). Modelling IT projects success: Emerging methodologies reviewed. *Technovation*, 27. doi:10.1016/j.technovation.2006.12.006
- Saghatforoush, E., Hosseini Nourzad, S. H., Zareravasan, A., & Jadidoleslami, S. (2023). Enablers for BIM application in architectural design: A robust exploratory factor analysis approach. *International Journal of Construction Management*, 23(9), 1549-1559. doi:10.1080/15623599.2021.1985775
- Saka, A. B., & Chan, D. W. (2023). BIM divide: an international comparative analysis of perceived barriers to implementation of BIM in the construction industry. *Journal of Engineering, Design and Technology*, 21(5), 1604-1632.
- Salmeron, J. L. (2009). Augmented fuzzy cognitive maps for modelling LMS critical success factors. *Know.-Based Syst.*, 22(4), 275–278. doi:10.1016/j.knosys.2009.01.002
- Salmeron, J. L. (2010). Modelling grey uncertainty with Fuzzy Grey Cognitive Maps. *Expert Syst. Appl.*, 37(12), 7581–7588. doi:10.1016/j.eswa.2010.04.085
- Samimpey, R., & Saghatforoush, E. (2024). Practical Framework to Facilitate Constructability Implementation Using Building Information Modeling Approach: A Case Study. *International Journal of Innovation & Technology Management*, 21(1).
- Sawhney, A., & Singhal, P. (2013). Drivers and barriers to the use of building information modelling in India. *International Journal of 3-D Information Modeling (IJ3DIM)*, 2(3), 46-63.
- Siddiqui, F., Akhund, M. A., Ali, T. H., Khahro, S. H., Khoso, A. R., & Imad, H. U. (2019). Barriers in Adoption of Building Information Modeling in Pakistan's Construction Industry. *Indian Journal of Science and Technology*, 12, 25.
- Siebelink, S., Voordijk, H., Endendijk, M., & Adriaanse, A. (2020). Understanding barriers to BIM implementation: Their impact across organizational levels in relation to BIM maturity. *Frontiers of Engineering Management*, 1-22. doi:10.1007/s42524-019-0088-2
- Tan, T., Chen, K., Xue, F., & Lu, W. (2019). Barriers to Building Information Modeling (BIM) implementation in China's prefabricated construction: An interpretive structural modeling (ISM) approach. *Journal of Cleaner Production*, 219, 949-959.
- Toyin, J. O., & Mewomo, M. C. (2023). An investigation of barriers to the application of building information modelling in Nigeria. *Journal of Engineering, Design and Technology*, 21(2), 442-468.
- Wang, X. (2012). *BIM Handbook: A guide to Building Information Modeling for owners, managers, designers, engineers and contractors*. *Construction Economics and Building*, 12(3), 101-102.
- Waqar, A., Othman, I. B., & Mansoor, M. S. (2024). Building information modeling (BIM) implementation and construction project success in Malaysian construction industry: mediating role of project control. *Engineering, Construction and Architectural Management*.
- Xirogiannis, G., & Glykas, M. (2004). Fuzzy cognitive maps in business analysis and performance-driven change. *IEEE Transactions on Engineering Management*, 51(3), 334-351. doi:10.1109/TEM.2004.830861
- Yaman, D., & Polat, S. (2009). A fuzzy cognitive map approach for effect-based operations: An illustrative case. *Information Sciences*, 179, 382-403. doi:10.1016/j.ins.2008.10.013

YAN, H., & DEMIAN, P. (2008). Benefits and barriers of building information modelling. Paper presented at the 12th International Conference on Computing in Civil and Building Engineering (ICCCBE XII) & 2008 International Conference on Information Technology in Construction (INCITE 2008), Beijing, China.

Yegnanarayana, B. (2009). Artificial neural networks: PHI Learning.

Zare Ravasan, A., & Mansouri, T. (2014). A FCM-based dynamic modeling of ERP implementation critical failure factors. *International Journal of Enterprise Information Systems*, Vol. 10 No. 1. doi:<https://doi.org/10.4018/ijeis.2014010103>.

Zareravasan, A., & Mansouri, T. (2015). A dynamic ERP critical failure factors modelling with FCM throughout project lifecycle phases. *Production Planning and Control*, 27. doi:10.1080/09537287.2015.1064551



APPENDIX A: THE LIST OF BIM MODELS

Row	Measure/ Source	(Liu et al., 2015)	(Kekana et al., 2014)	(M. R. Hosseini et al., 2015)	(El Hajj, Martínez Montes, & Jawad, 2023)	(Al-Zwainy et al., 2017)	(Sawhney & Singhal, 2013)	(Siddiqui et al., 2019)	(Hatem et al., 2018)	(Ariono, Wasesa, & Dhewanto, 2022)	(Hamidi Monozam et al., 2016)	(Mishra, Hasan, & Jha, 2024)	(Babatunde et al., 2020)	(Manzoor, Othman, Gardezi, Altan, & Abdalla, 2021)	(Chan, 2014)	(Oraee et al., 2019)	(Oteng et al., 2018)	(M. R. Hosseini, Azari, Tivendale, Banhashemi, & Chileshe, 2016)	(Hamma-adama et al., 2020)	(Enshassi & AbuHamra, 2017)	(Tan, Chen, Xue, & Lu, 2019)	(Bosch-Sijtsema et al., 2017)	(Siebelink et al., 2020)
1	Lack of transparency of the role and responsibility of individuals in entering information	√	√	√		√		√		√					√					√		√	
2	Team mentality and resistance to change among members of the organization/ cultural resistance in the company		√	√	√	√	√		√		√	√				√	√	√	√	√	√	√	√
3	Set-up costs	√	√		√	√	√	√	√	√	√		√	√	√		√	√	√	√	√	√	√
4	Misconception of the adequacy of traditional standards and methods	√	√	√	√	√		√	√	√	√			√	√	√	√	√	√		√		√
5	Poor collaboration between project practitioners/two-way interaction and transfer of information between project workgroups					√		√		√	√							√	√	√			
6	The cost of BIM training to employees			√	√	√	√	√	√			√	√					√	√	√	√	√	



7	Collection and integration of information due to the difficulty of access to the executives	√	√		√										√	√	√	√	√	√	√	√
8	Lack of awareness and support of senior management /lack of acceptance of BIM by senior management			√	√	√		√	√	√			√	√		√	√	√	√	√		
9	Consultant's unwillingness to use BIM		√	√	√			√		√	√	√				√	√	√	√		√	9
10	Cost of employing BIM specialists and additional staff	√		√	√	√			√								√	√	√	√		
11	The existence of other competitive methods				√								√			√			√		√	√
12	Distrust and fear of BIM technology and its unknowns				√	√	√	√		√					√							√
13	Lack of access to as built drawings	√				√																
14	The possibility of increasing risks (for example, legal cases)					√					√						√	√				
15	Lack of compatible data standards and formats/ incompatibility with common standards of this industry	√	√	√		√		√	√	√	√			√	√	√		√	√		√	√
16	Lack of maturity/non-applicability of BIM tools								√					√							√	
17	Poor data management	√				√	√		√	√					√	√	√			√	√	√
18	No guarantee for smaller projects to use BIM				√	√				√						√			√			√
19	Lack of a proper IT infrastructure							√				√					√	√			√	√
20	Lack of proper understanding of BIM	√	√	√	√	√	√	√	√			√		√		√			√	√		√
21	Lack of sufficient time to learn the software			√	√	√	√	√		√		√		√		√				√	√	√
22	Weakness in education			√	√	√	√	√	√		√		√	√	√						√	√
23	Insufficient experience in using BIM / lack of technical expertise	√	√	√	√	√	√	√	√	√		√		√		√	√	√	√	√		√

APPENDIX B: THE INTERRELATIONSHIPS AMONG CONSTRUCTABILITY OBSTACLES (INITIAL DATA)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23
A1		0.4						0.4	0.1				0.1	1		0.5			0.5			0.2	
A2	0.5																					0.2	
A3												0.2										0.2	
A4					0.1																		
A5								0.2															
A6	0.2							0.2		0.2													
A7																0.2							
A8						1						0.2			0.2		0.2		0.2				
A9																							
A10																			0.2				
A11	0.2					0.2							0.6										
A12					0.2									0.2					0.2				
A13	0.2																						
A14												0.2				0.4							
A15																						0.1	
A16		0.2																				1	
A17																							
A18													0.1										
A19	1																	0.2					
A20							0.2																
A21													0.2										
A22	1						0.5															0.2	
A23										0.2			0.5										



APPENDIX C: THE LINK FROM OBSTACLES' CONSEQUENCES (EI) TO PROJECT FAILURE MODES (FI) (INITIAL DATA)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
A1	0.2	0	0.1	0	0	0	0	0	0	0
A2	0.2	0.2	0	0.2	0	0	0	0	0	0
A3	0.1	0	0	0.2	0	0.2	0	0	0	0
A4	0	0	0	0.2	0	0	0	0	0	0
A5	0	0	0	0	0	0.2	0	0	0	0
A6	0	0	0	0.2	0	0.4	0	0	0	0
A7	0	0	0	0	0	0	0	0.2	0	0
A8	0	0	0	0	0	0	0	0	0	0
A9	0	0.4	0.2	0	0	0	0	0	0.2	0.2
A10	0	0	0	0	0.2	0	0.2	0	0	0
A11	0	0	0	0	0.2	0	0	0	0.2	0
A12	0	0	0	0.2	0	0	0	0	0	0.2
A13	0.2	0	0.2	0.2	0	0	0	0.2	0	0
A14	0.2	0	0	0	0	0	0	0	0	0
A15	0	0	0	0.2	0	0	0	0	0	0
A16	0.2	0	0.2	0	0	0.2	0	0	0	0
A17	0	0	0	0.2	0	0	0	0	0.2	0
A18	0	0	0	0	0	0	0	0	0	0
A19	0	0	0	0	0	0.2	0	0	0	0
A20	0	0	0	0	0	0.2	0	0	0	0
A21	0	0	0	0	0	0	0	0	0.2	0
A22	0	0	0	0.4	0	0.1	0	0	0	0
A23	0	0	0	0	0	0.2	0	0	0	0

APPENDIX D: THE LINK FROM OBSTACLES' CONSEQUENCES (EI) TO PROJECT FAILURE MODES (FI) (INITIAL DATA)

	Time	Cost	Quality
E1	0.5	0	0.2
E2	0	0.2	0
E3	0	0.1	0
E4	0.1	0	0
E5	0.1	0	0.1
E6	0	0.2	0.1
E7	0	0	0.2
E8	0.1	0	0
E9	0	1	0.1
E10	0.4	0	0.1