Barriers and Risks in BIM-Embedded Design Collaboration: A Two-Mode Social Network Analysis

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Abstract: The construction industry has always been criticized for fragmentation arising from the separated design and construction processes. Although Building Information Modeling (BIM) is considered to be beneficial for effective collaboration through the lifecycle of construction projects, the BIM-embedded design collaboration is still problematic. The aims of this study are a) investigating the relationships between the key risks and barriers in GBA setting from users` perspective, and b) applying the Social Network Analysis (SNA) methods to visualize the barriers and risks in network structure.

This paper applies a two-mode social network analysis (SNA) to investigate the key barriers and risks and to understand their relationship in BIM-embedded design collaboration in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) context. Two independent construction projects were investigated, and five face-to-face and online semi-structured interviews were conducted with experienced design management team members. In this study, the barriers are the reasons that cause the risks, and the risks indicate the poor project performance in BIM-embedded collaboration. Based on the collected dataset, six key barriers as actors and ten risks as the events have been considered; the resultant matrix for investigation is a 6 × 10 matrix, representing a two-mode social network.

The results suggest that promoting a collaborative culture is vital for project managers to deliver construction projects in the BIM vision in the company-level. On this basis, the evaluation of company internal design coordination should be taken into account when BIM integration. Moreover, the findings of this research highlight the key barriers as lack of trust and share, fragmented work, multiple silos and different understanding of BIM; plus, the risks of the difficulty in model management, miscommunication and increased short-term reworks received more impacts on impeding BIM-embedded design collaborations. Recommendations were given at the end of this paper for breaking the chains of unfavorable causations for high-quality construction project management.

Keywords: BIM-embedded collaboration; social network analysis (SNA); design management; two-mode network.

1 Introduction

Digital technologies have been acknowledged for enabling better collaboration and data-driven decision making in design management (Benner & McArthur, 2019; Pan & Zhang, 2021). Many design and construction companies are adopting Building Information Modeling (BIM) to reduce exposure to risks and additional project cost for the client, significantly improve the effectiveness of operations and activities during design management (Blay et al., 2019; Santos et al., 2017). However, in the construction industry, the opinions among the design management professionals on the benefits of BIM-embedded collaboration is very sporadic. Although the current literature indicates numerous barriers and risks recognized by construction practitioners associated with BIM implementation, how these barriers hinder the benefits and causes risks is not entirely known among professionals.

Meanwhile, the increasing complexity in modern construction projects and the involvement of multitude stakeholders require substantial information technology (IT) capabilities to support collaboration design works among design team members. However, how these IT capabilities create the practical benefits for design management remains unclear in the architecture, engineering, construction and operations (AECO) industry (Doloi et al., 2015; Oti et al., 2016). BIM has been considered as a critical technology-oriented process innovation in the last decade(Bianchini et al., 2017). Especially BIM-embedded construction projects are extremely expected to achieve highly efficient coordination and to alleviate multiple silos works. Therefore, in order to understand the relationship of risks and barriers related BIM integration, investigating the underlying impediments is highly crucial for making informed decisions in BIM-embedded design coordination.

Given the fact that the aims of the Greater Bay Area (GBA) city cluster are to establish close links between nine provincial cities in Guangdong province and the Hong Kong and Macao, and to develop an economic zone which will be a crucial component in the next phase of China's economic development. Therefore, substantial buildings and infrastructure must be put in place to connect the various areas of this complex and diverse region. Meanwhile, it is also an opportunity for Hong Kong to capitalise on the expertise and experience it has obtained in the construction field over the past decades. However, a lot of construction projects in GBA are or will be delivered through co-operation between mainland China teams and Hong Kong teams. It is difficult to deliver a positive outcome for all sides, especially regarding to reach agreements in various regulations and industry codes of practice. Thus, this collaboration is very important and understanding the risks and barriers in BIM-embedded collaboration in different parts of the GBA will be crucial to achieve the true benefits of BIM implementation for companies.

Existing studies have pointed out that improved communication techniques for construction design management might only contribute slightly to cohesion and coordination in the construction project team (Dossick & Neff, 2011; Gu et al., 2008; Oraee et al., 2019). For example, Al Hattab and Hamzeh (Al Hattab & Hamzeh, 2015) indicate that the positive benefits of BIM for design management are primarily limited to the technological level, and the essential factors that are inhibiting BIM integration are still the people-related factors, such as lack of information sharing and collective culture. Thus, understanding the patterns of barriers and risks associated with BIM integration have a significant influence on design collaboration. In this study, the barriers are the reasons that cause the risks, and the risks indicate the poor project performance in BIM-embedded collaboration.

The aims of this study are a) investigating the relationships between the key risks and barriers in GBA setting from users` perspective, and b) applying the Social Network Analysis (SNA) methods to visualize the barriers and risks in network structure. The remainder of this paper is organized as follows. Section 2 briefs the application of Social Network Analysis (SNA) and the three steps of this study. Six barriers and ten risks are mapped in Section 3 as network models. Results and analyses of the SNA are presented in Section 4. Discussion and conclusion appear in Sections 5 and 7, respectively.

2 Application of Social Network Analysis (SNA)

Social Network Analysis (SNA) applies graph theories and network modelling techniques to investigate the characteristics of social networks. A social network is a set of relevant nodes connected by one or more relations (Scott & Carrington, 2011). In other words, a social network comprises a finite sets of nodes and the relations defined on them. In the construction industry, social network analysis is progressively used by researchers because of the multitude participants collaborating and interrelating for various complex construction projects with intense communications (Park et al., 2011; Pryke, 2005). Therefore, social network analysis provides a unique platform to integrate barriers and risks of BIM-embedded collaboration.

Nodes, links and network attributes are three vital concepts to understand social network analysis. In the network, 'nodes' or actors could represent persons, groups or events as entities in the investigated network. The 'links' or relations between the nodes represent the various kinds of relationships such as exchange information, friendships, trust bonding or money transfers (Ruan et al., 2012). One crucial characteristic of a network is the node 'degree centrality', which is a measurement of the number of links or ties that the node has. Networks might have one or several central nodes with links to other nodes, representing high or low 'degree centrality'. If the links have direction, which called directed network, then two separate measures of degree centrality are defined, specifically, indegree and outdegree. A central position within the network signifies the importance throughout the network and the capability for accessing other nodes (Doloi et al., 2015; Zheng et al., 2016). Consequently, which different structure positions (such as central, connecting, isolate) of nodes, SNA could be applied to map the relevant networks and to examine the prominence of different nodes.

Conventionally, one-mode SNA was implemented in the literature. Most networks are defined as one-mode network because of the similar kind of nodes in the networks. Numerous pieces of literature have discussed the analysis process of one-mode network (Al Hattab & Hamzeh, 2015; Wang et al., 2020). One-mode network analysis depicts every node interact with each other in a square matrix. This kind of network is very useful to identify the social connection between nodes and to study the network measures such as influence, power and cluster etc. However, some studies require analyzing two kinds of nodes, typically events and attendees or group members and groups, which eventually result in a two-mode network (i.e., affiliation or bipartite networks).

This study aims to apply a two-mode SNA to the key barriers and risks in the GBA setting from the users’ perspective. With intense communication and multifaceted activities among project team members, the power of SNA provides a visual network structure for investigating the various links and complicated interactions between the processes of construction project delivery.

Regarding the various perceptions of BIM-embedded collaboration for design management, based on the previous literature and the interviews in this study. Six key barriers as actors and ten risks as the events have been considered. The resultant two-mode SNA matrix for investigation is a 6 × 10 matrix. These factors are mapped based on the interviewees` understanding of the interactions between the barriers and risks in the BIM integration context.

2.1 Research Steps

Two assumptions were formed to fulfill the propose of this study. Hypothesis 1: Currently, BIM-embedded collaboration in design management still problematic as some key barriers related to people. Hypothesis 2: Benefits of BIM integration in design management are governed by multiple layers of interdependent factors associated with the BIM-embedded collaboration barriers and risks network.

Figure 1 shows the case study approach adopted in this paper. It is, overall, an exploratory study of finding prominence of barriers that cause risks; therefore a case study approach is appropriate for investigating such a contemporary phenomenon within some real-life context(Zhang et al., 2013). The three steps are data collection, network modeling and network analysis.

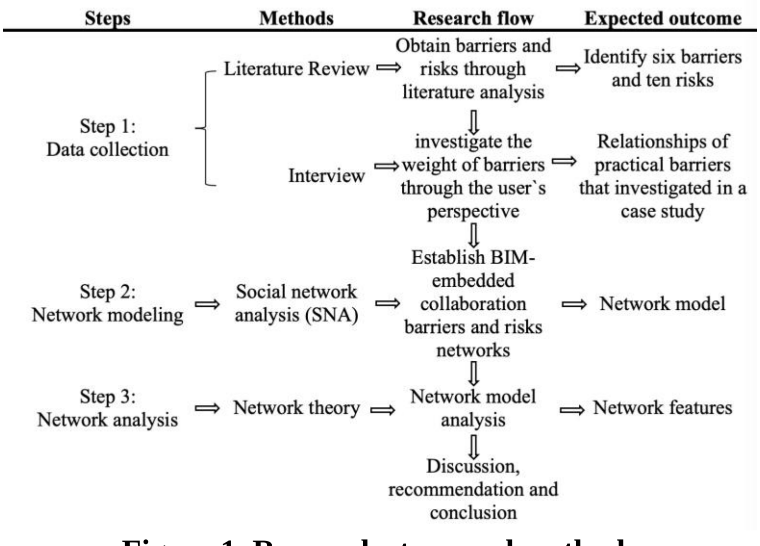


Figure 1. Research steps and methods

Two cases were investigated, from two independent construction projects located at the GBA, as listed in Table 1. The types of barriers and risks were collected from the related literature, and verified with five semi-structured interviews and documentation review. The interviews were conducted with design management team members who have had at least of 3-years of BIM-embedded collaboration experience. Before commencing the interview, the interviewees were requested to complete a questionnaire using a 5-point Likert scale to preliminarily answer the weight of barriers through the user`s perspective. After the interview, interviewees were required to review the questionnaire again to ensure their final opinions were reflected.

	Project A	Project B
Project type	Office & Hotel	Residential Buildings
Duration (still ongoing)	3 years	5 years
Procurement models	Design–bid–build (DBB)	Design–bid–build (DBB)
GFA	130,134 sq^m	502,660 sq^m
Finance	Private	Private

Table 1. Overview of the project information

3 The Network Models

Table 2 illustrates the six key barriers and the ten key risks investigated in this study, which are the nodes in the investigated networks. In this study, the barriers are the reasons that cause the risks, and the risks indicate the poor project performance in BIM-embedded collaboration. The first step of modelling networks is mapping these nodes regarding their impacts and influence on one another in the BIM integration process. In this research, the key barriers and the key risks were associated using a 5-point Likert scale. Six key barriers being the actors and ten risks being the events. The resultant matrix for investigation is a 6x10 matrix which is naturally an affiliated network or two-mode network. Each respondent was required to fill the questionnaire about the weight of links between the barriers and risks. Table 3 demonstrates the average weights of links in the 6x10 unsymmetrical matrix. The BIM-embedded collaboration barriers and risks network was established.

Key Barriers	Key Risks
B1: Reluctance to learn something new	R1: Rise in short term cost
B2: Lack of trust and share	R2: Difficulty in model management
B3: Different understanding of BIM	R3: Increased short-term reworks
B4: Fragmented work, multiple silos	R4: Difficulty in design changes management
B5: Blame others	R5: Lack of skilled personnel
B6: Reluctance to follow BIM standards	R6: Unclear contracts liability
	R7: Difficult to trackback
	R8: Miscommunication
	R9: Difficulty in Workflow transition
	R10: Outsourcing modelling servicers

Table 2. Key barriers and risks associated with BIM-embedded collaboration

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
B1	2.167	3.833	3.500	2.000	3.833	1.333	2.833	2.333	2.333	2.167
B2	2.667	3.167	3.167	2.333	2.167	3.167	3.500	4.000	2.500	1.667
B3	2.667	3.167	3.167	2.000	2.833	2.667	2.000	3.333	3.167	2.000
B4	2.333	3.167	2.833	2.833	2.667	1.333	3.000	2.333	3.167	3.500
B5	1.500	3.000	2.500	2.333	2.000	3.333	3.500	3.500	3.333	1.667
B6	2.333	3.333	2.833	2.333	2.833	3.333	2.167	3.000	3.167	1.500

Table 3. The 6x10 unsymmetrical matrix

4 Analytical Results

4.1 Affiliation Analysis Between Barriers and Risks

Design professionals have reached a consensus that understanding various barriers and risks of BIM-embedded collaboration is vital to delivering efficient design management (Hickethier et al., 2013; Wu et al., 2013). However, how the barriers, especially factors related to people, causes risks of BIM integration are quite important to investigate. Affiliation network analysis provides a useful method to establish the relations between the risks and the barriers which have influences on the events. Based on the SNA methodology, the bipartite network is easy to visualize by implementing the affiliation analysis on the two-mode matrix (Scott & Carrington, 2011).

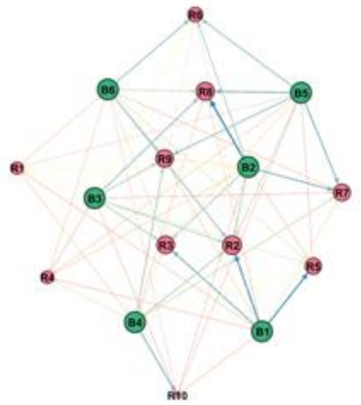


Figure 2 Relationship between barriers and risks in the network map

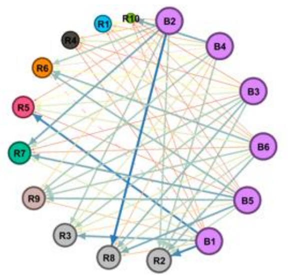
Figure 2 illustrates the network structures between six barriers and ten risks factors within BIM-embedded collaboration in construction projects. Seemingly, the green dots are the six barriers, and the red dots are the ten risks, and the sizes of the dots represent the prominence of each node within the interactions. The directions and links represent the influence between the barriers and the risks, and the thickness of the links represent the weight of impacts from one barrier to one risk as illustrated by the arrows. Therefore, the links and arrows in the figure demonstrate to what extent the barriers related to people causing the risks for BIM integration. Based on SNA measures, such prominence and criticality of both barriers and risks can be quantified as the weighted degree.

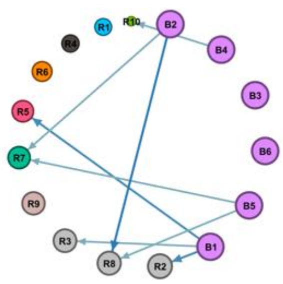
Table 4 demonstrates the respective weighted degree of all barriers and risks derived from the network analysis. Evidently, the most crucial barriers related to people in BIM-embedded collaboration corresponding to the highest weighted degree values were found to be B2 (Lack of trust and share), B4 (Fragmented work, multiple silos) and B3 (Different understanding of BIM). Similarly, R2 (Difficulty in model management), R8 (Miscommunication), R3 (Increased short-term reworks), R9 (Difficulty in Workflow transition) and R7 (Difficult to trackback) with higher weighted degree values were found to be highly affected risks in the BIM implementation context. On the other extreme, B1 (Reluctance to learn something new), B5 (Blame others) and B6 (Reluctance to follow BIM standards) with lower weighted degree values are the least critical barriers in the BIM-embedded collaboration process. Correspondingly, R10 (Outsourcing modelling servicers), R1 (Rise in short term cost), R4 (Difficulty in design changes management), R6 (Unclear contracts liability) and R5 (Lack of skilled personnel) with the lowest weighted degree values were found to be the least influential risks for implementing BIM for design management.

Key Barriers	weighted out-degree	Key Risks	weighted in-degree
B2	28.335	R2	19.667
B4	27.166	R8	18.499
B3	27.001	R3	18
B6	26.832	R9	17.667
B5	26.666	R7	17
B1	26.332	R5	16.333
		R6	15.166
		R4	13.832
		R1	13.667
		R10	12.501

Table 4 Weighted degree of barriers and risks in two-mode network analysis

Figure 3 demonstrates the circular layout of the barriers and risks of a BIM-embedded collaboration network. One advantage of a circular layout is its neutrality. No node is placed at a privileges position because all vertices are put at equal distances from each other. It is evidently to show the thickness of the links, which represent the weights of influence from barriers to risks in BIM implementation. As seen in Figure 4 and Figure 5, the strongest impacts between barriers and risks corresponding to the largest weight of link were found to be B2 (Lack of trust and share) to R8 (Miscommunication), B1 (Reluctance to learn something new) to R2 (Difficulty in model management) and B1 (Reluctance to learn something new) to R5 (Lack of skilled personnel). Similarly, B1 (Reluctance to learn something new) to R6 (Unclear contracts liability), B4 (Fragmented work, multiple silos) to R6 (Unclear contracts liability), B5 (Blame others) to R1 (Rise in short term cost) and B6 (Reluctance to follow BIM standards) to R10 (Outsourcing modelling servicers) with a smaller weight of link were found to be weaker impacts between barriers and risks for BIM-embedded collaboration.





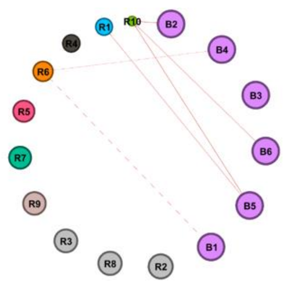


Figure 3 Circular layout of the barriers and risks network(left)
Figure 4 larger weight of links in the network (middle)
Figure 5 smaller weight of links in the network (right)

4.2 Modularity Analysis

Modularity analysis was performed to understand the clustering effects of both barriers and risks within the network structure. As seen in Figure 6, the biggest group contains three barriers (B2, B6 and B5) and five risk instances (R8, R7, R9, R6 and R1). The second big group comprising two barriers (B3 and B1) and three risks (R2, R3 and R5). The remaining barrier B4 and two risks, namely R4 and R10, formed the smallest group.

These findings indicate how the combined impacts of the barriers and risks can affect the construction projects from a collective perspective. Moreover, these results might provide a better basis for decision making in BIM-embedded design management. Regarding the interactions of barriers and risks of BIM integration with the group's analysis, decision-makers might apply reasonable strategies to ensure higher effectiveness and improve the performance of design management.

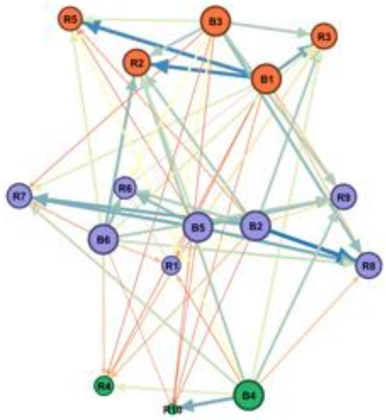


Figure 6 Modularity of barriers and risks within the network structure

5 Discussion

Regarding the results of affiliation analysis between barriers and risks in BIM-embedded collaboration, this study might have serval important managerial implications. Obviously, the top three crucial barriers that creating largely risks in the BIM integration process are B2 (Lack of trust and share), B4 (Fragmented work, multiple silos) and B3 (Different understanding of BIM). To achieve high effectiveness of design management, on the one hand, a design manager could investigate the task teams to see whether task-related communication among the participants come from different disciplines is both trustworthy and transparent. On the other hand, the top two biggest risks impeding BIM-embedded collaboration are R2 (Difficulty in model management) and R8 (Miscommunication). Consequently, by improving the transparency of sharing information and leverage BIM standards embedded collaboration platform, design team members might facilitate communication and information interoperability.

With regard to the weights of links between barriers and risks, namely the top three B2 (Lack of trust and share) to R8 (Miscommunication), B1 (Reluctance to learn something new) to R2 (Difficulty in model management) and to R5 (Lack of skilled personnel). The findings also demonstrate that vital human factors such as lacking trust and improvements might result in miscommunication within participants, problematical 3D model management and inadequate experienced personnel. Evidently, by delivering qualified training, examining the training outcomes regularly and following up feedbacks from trainee, project managers might gain more controls for avoiding risks impeding BIM integration. Moreover, using the analytical methods conducted in this study, project managers could assess the effectiveness of design management via the strength of the links between barriers and risks within the network structure.

From these findings, the barriers which are listed as important are more company or industry-level barriers, while others (B1, B5, and B6) are more individual-level. All interviewees agree that project members prefer blame to others who do not work for same company, especially issues related to design change. Although it is a conventional phenomenon in design management, individuals still choose to blame others even with BIM integration that allowing works can be tracked back easily. Consequently, promoting a collaborative culture is vital for project managers to deliver project in the BIM vision.

6 Limitation

Nevertheless, there are several limitations in this study. It is, overall, a small-scale pilot study of examining the prominence of barriers that cause risks. As time limited, the 6 × 10 investigation matrix is formed based on only five respondents and in the GBA context. Although this study has illustrated the methodological progress, particularly the SNA methods, by managing and quantifying the impacts between the barriers and risks for impeding effective BIM-embedded collaboration, the inadequate empirical validation makes the findings someway inconclusive. Therefore, the results should be further reviewed and assessed with empirical data in the construction industry context.

7 Conclusion

Barriers and risks still impede the design collaboration in construction project management, even with the latest embedment of BIM. This research adopts a two-mode SNA to the analysis of the barriers and risks, and their relationship, in BIM-embedded collaboration in design management. A total of six barriers have been identified, and ten risks as the impediments in BIM integration have been investigated based on a previous literature review. Data were collected from experienced participants on one-to-one interviews to quantify the weight of links between the barriers and risks in a typical construction context. Social network analysis was applied using the Gephi 0.9.2 software package, and fundamental SNA measures were calculated. The findings confirm the hypotheses that BIM integration in design management is problematic because of the key barriers such as lacking trust, fragmented works and different understandings of BIM. Moreover, the results of analyzing relationships between barriers and risks impeding BIM-embedded collaboration are expected to assist the decision-makers to adopt appropriate approaches to fulfil the benefits upon BIM integrated design management.

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