Drivers And Impediments Of Building Information Modelling From A Social Network Perspective

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ABSTRACT

While Building Information Modelling (BIM) is considered to be highly beneficial for managing construction projects over initiation to completion phases, the perception among the professionals is quite diverse especially in the Australian Construction context. Such a diverse viewpoint is due to lack of objective analysis of cost versus benefits and as a result the decision on up taking the BIM interface among the multitude of stakeholders becomes quite fuzzy. While the consultants in most projects are quite pushing the move for BIM enabled project management, other key players such as tier 2 and 3 contractors and numerous sub-contractors often consider the investment in BIM as somewhat wasteful. In an attempt to understand the drivers and impediments of BIM uptake especially among the tier 2 and 3 contractors in Australian construction industry, this research focuses on the social network theory to investigate the impediments associated against the BIM functionalities within the project. Based on the social network theory, the finding of the research will highlight the key impediments and their relative influence on the drivers hindering the BIM integration in construction projects. The findings are expected to provide a methodological advancement in visualising the impacts of driving and impeding factors and assist in greater understanding of the risks associated in achieving the true benefits of BIM being implemented in construction projects.

Keywords:
BIM, SNA, Risks, Drivers of BIM

1 Introduction

Building Information Modelling (BIM) is one of the key enabling considerations in 21st century construction projects and the uptake of BIM is growing at an exponential rate across the globe. In Australian construction industry however, the perception among the construction professionals on the benefits the BIM being implemented onto the project is quite sporadic. While the current literature suggests numerous risks perceived by the construction community associated with the BIM integration, how these risks hinder the underlying drivers is not quite known within the profession.

Given the fact that the perceptions of BIM integration and the underlying benefits are quite diverse among the construction community, this research aims to highlight the key drivers and impediments from the users' perspectives. Based on the literature review, a total of ten key driving factors have been identified. Regarding the impediments, a total of 13 risk factors as reported in Chien *et al* (2014) have been considered. Utilising the Social Network Analysis (SNA), these factors are mapped based on the users' perceived understanding on the associations and mutual impacts in the BIM integration perspective.

2 Research Background

Risk management in construction is a well published topic. However, due to rapid evolution of construction technology particularly computer aided design and augmentation of virtual reality, the current best practice knowledge is not quite relevant in dealing with emerging risks associated with such innovations within the industry. Increasing complexity in modern construction projects demands significant IT capabilities, however how such capability brings about the positive changes in the industry remain unclear among the construction community. Empirical evidences on quantified benefits derived from IT integration in construction are still not quite widespread.

Among numerous emerging IT capabilities, BIM is considered to be one of the key enablers for comprehensive identification of risks and meeting the intended project objectives among the stakeholders. In order for understanding the drivers and impediments associated with the BIM integration, realistic evaluation of the underlying risks is highly crucial.

While drivers associated with BIM integration is relatively easy to identify, the impediments are difficult to ascertain. Many researchers often consider risks and impediments as the two sides of the same coin. Effective risk management in construction can potentially result in the benefits which may not be otherwise realised at all. If the risks are left undetected, eventualities of risks could potentially jeopardise the performance of project at multiple level (Ghosh and Jintanapakanont 2004). On the other hand, proactive action on the risk management front could potentially open up numerous oppportunities with the industry. Thus understanding of both drivers and risks as being impediments is absolutely necessary for making informed decision around BIM integration in construction projects.

A systematic approach to risk management requires not only to simply identifying the risks but also evaluation of control and mitigation strategies in a dynamic manner (Wang et al. 2004). As evident in the risk management literature, current risk management practices are usually of two folds, qualitative and quantitative (Zhi 1995). The key focus for qualitative risk assessment is on visual observation and ad-hoc estimates of probability of occurrence and potential impacts should a particular event occurs. As such an approach puts significant responsibilities on the risk assessors, the accuracy relies on historical trends of risks in similar projects. Due to increasing complexity of the modern construction projects and involvement of multitude of stakeholders over the lifecycle, qualitative assessment cannot be considered exhaustive for addressing the risks and ensuring the competitive advantage. One of the challenges in modern projects is the highly contractual relationships among the parties and custodian nature of responsibility assignment in projects. In such a situation, some sort of quantification of risks commensurate the contractual roles and share of responsibilities is highly important for accurate allocation and management. In addition, having inherited a risk, how could a stakeholder potentially affect others in the contractual arrangement within a project is an important area for investigation. For instance, financial risks in a typical project do not belong to a single stakeholder but it would affect quite wider groups of stakeholders in and beyond the project lifecycle. Thus, it is important to assess the ripples of such risks and propagation of impacts so that appropriate intervention can be devised for containing the risks at an early stage of the project.

In complex projects with many stakeholders, application of Social Network Analysis (SNA) provides a unique platform for integrating the stakeholders and the construction risks holistically. Three concepts are of vital importance in understanding the social network analysis, nodes, links and network measures. In the network, the 'Nodes' or 'Actors' are entities, persons, organisations, or events. The 'Links' between the nodes represent the relationships of any kind such as transfer of money, communications, friendships, exchange of resources or information etc. (Borgatti and Everett 1997). One of the key characteristics of the network is the 'node centrality' which is a measure of degree of connectivity within the network. Networks may have one or several or even no central actor(s) with links from many actors directed to it, which represents high or low network 'centrality'. A central position within the network indicates the amount of power obtained through the structure and capacity to access information and the other members (Doloi 2012). Thus, SNA is concerned with the structural positions (such as central, isolate, bridging etc.) of actors. If an actor has many links to others in the system, then it has different network characteristics than an actor with fewer links within the system.

SNA has been applied to analyse the needs of stakeholders and assist decision making (Doloi 2012). Realising the intrinsic benefits of the SNA methodology, this research adopts an SNA based methodology for investigating the interactions of stakeholders' within BIM integration risks in construction projects. For the sake of brevity, details of the SNA methods are not discussed in this manuscript.

3 Theoretical framework of the research

The theoretical underpinnings of the proposed research have been conceptualised around two clear hypothetical constructs as follows:

Hypothesis 1: Benefits of BIM integration in construction projects are governed by multiple layers of interdependent driving factors associated with the stakeholders' networks.

Hypothesis 2: Driving and impeding factors associated with BIM integration are interlinked and the influence of these factors on the project outcomes is mutually inclusive.

The hypothesis requires viewing the perceptions of stakeholders on both driving and impeding factors from a network perspective. It has been postulated that both driving and impeding factors are intrinsically linked to the perceived social network structure within the construction community. The traditional viewpoint of benefit propositions and risks management in isolation is not necessarily be able to provide with any reasonable understanding on the benefits being realised upon BIM integration is projects. Due to the virtue of these factors being linked to stakeholders' perceptions, they need to be assessed in relation to one another within a network structure of risks. It is assumed that the ability of a stakeholder managing risks grossly depends on the social connection and interactions with other stakeholders in the project and an effective management of these risks would potentially result in positive benefits in the project. By the virtue of centrality measures being the measurer of powers and influence of actors with a network, hypothesis 2 aims to unfold the relative rankings of both driving and impeding factors in relation to perceived stakeholders' influence in the order of their centrality values and potential importance in the project. It has been hypothesised that both driving and impeding factors have legitimate connections and their influence of power on one another is governed by the centrality values within the network structure.

4 Application of Social Network Analysis (SNA) in Construction

SNA implies system approach for constructing the relationship patterns between actors rather than identifying individual attributes of each entity (Borgatti and Everett 1997). It is becoming increasingly popular methodology for understanding and mapping the complex patterns of actors' interactions within a network system. SNA has been applied to identify the relative stakes of actors and various functional units in the study of organisational dynamics and similar management issues. However, application of SNA is not quite widespread in construction industry. While multifaceted activities among stakeholders and intense communication exert enormous management challenges, the power of SNA provides a novel basis for investigating the dyadic ties and complex interactions between the stakeholder and the processes in delivery of construction projects (Doloi 2012, Pryke 2005).

Social Network Analysis was used as a research method for analysing the three networks, namely risk-stakeholders network, risk-risk network and stakeholder-stakeholder network. The first step of any network model is the collection of appropriate data by identifying the nodes and the links. In this research, the main nodes are the thirteen risks and the sub-nodes are the seventeen stakeholders as presented in Table 1. While the primary data is required for accurate representation of the empirical phenomena, collection of primary data requires significant effort and stringent protocols. Due to lack of appropriate resources for collecting the primary data and the fact that the novelty of the research lies with the demonstration of the social network based methodology, the secondary data was considered to be appropriate for this research. The secondary data was collected based on published literature where the drivers and the impediments were associated using a 5-point Likert scale. Two data points were collected for mapping the impacts of risks on the driving factors with respect to the probability of occurrence and the impacts.

4.1 Centrality Measures

Among the range of SNA measures, centrality is a measure of the location and the importance of a within a specified network structure. Thus the centrality represents the sum of direct ties to other actors in a network. In a social network, centrality has been defined by leading social network researcher as a measurement of importance, prominence and influence of actor in a network (Borgatti and Everett 1997). Strong and extensive ties to other nodes in the network indicate that the one stakeholder is more likely to influence others with respect to a project environment, thus more important (central) in the network. Therefore, stakeholder who is communicated for providing information to conducting the construction process is more likely to influence others and become central in the network (Chinowsky et al 2008).

In the SNA methodology, there are a range of centrality measures available namely degree centrality, closeness centrality, betweenness centrality or eigenvalue centrality. Researchers have used all these centrality measures in order for representing the strength of a particular node within the network structure. The degree centrality can be viewed as an indicator of an actor's communication activity or popularity that is measured simply through the number of connectivity with other nodes in the network. The degree of a node is simply the number of other nodes connected directly to the node (Pryke 2005).

While the degree centrality is kind of a local centrality, closeness centrality is a global centrality measure in terms of the distance along various nodes. The node is called to be globally central if it lies at the shortest or closet distance from all other nodes in the network. Another concept of node centrality is the betweenness centrality which measures the number of times a particular node lies 'between' the various nodes in the network. This is thus the measure of the 'number of shortest paths that pass through a given node'

(Borgatti and Everett 1997). Taking into consideration of the relative positioning of a central node with respective to adjacent nodes with high degree centrality, Pryke (2005) suggests that a high eigenvector centrality is a significant measure representing the versatility of a node within the network. For the sake of brevity, the details of mathematical expressions of all these centrality measures have not been included in this manuscript and can be found in number of mainstream literatures including Borgatti and Everett (1997) and Doloi (2012).

4.2 Drivers and Impediments in BIM implementation process

While numerous assertions have been put forward by the researchers around integration of BIM in construction projects, there is clearly no single consensus on quantified benefits among the construction stakeholders. Regarding the driving and impeding factors and their influence on the project outcomes, there has been numerous industry-based evidence within the current body of literature. However, such factors have been mostly studied in isolation without looking at the interdependencies especially from the stakeholders' perspective.

Table 1 Key Drivers and Risks associated with BIM

Key Drivers	Key Risks *(source: Chien et al 2014)*
D1:Effective collaboration	R1: Inadequate project experience
D2: Output/man hour	R2:Lack of software compatibility
D3: On time completion	R3: Difficulty in model management
D4: Safety management	R4: Inefficient data interoperability
D5: Within budget delivery	R5: Inflexibility in management processes
D6: Avoidance of Rework	R6:Inadequate management commitments
D7: Quality Control	R7: Workflow transition difficulty
D8: Effective Design Management	R8: Lack of skill personnel
D9: Efficient procurement management	R9: Increased short term workload
D10: Efficient Contract Management	R10: Rise in short term cost
	R11: Additional expenditure
	R12: Lack of BIM standard
	R13: Unclear legal liability

One of the notable observations that both driving and impeding factors are the perceptions of the same groups of stakeholders within a particular context has been oversighted in most BIM based research to date. In an attempt to fill this knowledge gap, this research identified ten key driving factors and thirteen key impeding factors from the published literature. The impeding factors in this research refer to the risks associated with the BIM and these factors have been taken from a specific source namely Chien et al (2014). The aim is to investigate both the driving and impeding factors in relation to the stakeholder's associations and their cascading impacts on one another within the stakeholders' networks.

Ideally, the perceptions of the key stakeholders in relation to the BIM integration aspect need to be gathered for relevant empirical testing of the links and associations of the factors. However, such an empirical testing requires quite a significant effort which was not quite possible during the time of developing this manuscript. Thus, in this current research, the perceptions of the key stakeholders in relation to the BIM integration has been tested by taking into consideration of one expert's viewpoint for demonstration of the methodological development. The remainder of the paper will focus on the demonstration of the methodology with a hypothetical dataset.

4.3 Network models and visualisations

Table 1 depicts the 10 driving factors and 13 impeding (risks) factors used in the research. As a first step in the network based research analysis, these factors need to be associated in relation to their impacts and influence on one another using a Likert scale. Using a 5-point Likert scale, the driving factors (being the actors in the network analysis) have been associated with the risks or impeding factors (being the events in the network analysis) mapping the impacts of risks on the drivers in the BIM integration process.

Network analysis is usually carried out on 1-mode or square matrix. The process of 1-mode network analysis is widely discussed in SNA literature. The 1-mode network analysis depicts the square matrix where every node (or actor) is measured against other nodes within the symmetrical network. Such a network is quite powerful in finding the social connections between the actors and eventually to study the numerous network measures such as power, influence, groupings etc. However, when an actor is required to study against an event, the actors and the events are considered as nodes in their respective networks. In reality, the number of actors associated with a set of events would possibly form an unsymmetrical matrix due to the number of actors and events are not necessarily to be same which eventually results in a 2-mode network. In SNA literature, such 2-mode network is often refereed as the affiliated networks or membership networks comprising set of actors involved in a set of social events (Knoke and Yang 2008).

In this research, 10 driving factors being the actors and 13 impeding or risks factors being the events, the resultant matrix for investigation is a 10x13 matrix which is naturally an affiliated network. The theories of the affiliated network analysis have been clearly discussed in sources such as Knoke and Yang (2008). Following sections will discuss the analysis and discussions associated with the affiliated networks as adopted in the current research.

4.3.1 Affiliation Analysis between drivers and impediments

While the understanding of different risks in BIM integration context is reasonable among the professionals and such risks can potentially be addressed from a traditional risk management approach, how these risk events hinder the driving factors being not realised within the construction projects is an important topic for investigation. Affiliation network analysis is quite a powerful tool to establish the links between the risks and the drivers which could potential ascertain the impacts and influences of the events on the actors. In the SNA approach, such affiliated network is easy to visualise by performing the Bipartite matrix analysis on the 2-mode dataset (Knoke and Yang 2008). The brief theory on bipartite analysis is discussed in Doloi and Varghese (2015).

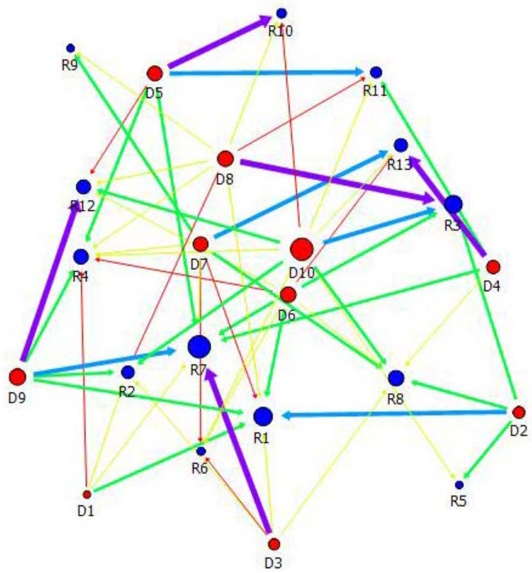

Figure 1. Relationships between drivers and impediments in Network Map

Figure 1 depicts the sociograms between 10 driving factors and 13 risks factors within the BIM integration process in construction project. As seen, the red dots are the driving factors and the blue dots are the risks or impeding factors and the sizes of the dots represent the importance of respective actors within the interactions.

The links and directions between the actors show the impact and the thickness of the links represent the degree of impacts or tie strenghts from one actor upon another as depicted by the arrows. Thus the arrows and the links in the diagram show how the risks factors associated with the BIM integration affect the driving factors. Such criticality and importance of both risks and driving factors are based on the eigenvector centrality values derived from the SNA models.

Table 2 shows the respective eigenvector centrality of all risks and driving factors derived from the SNA model. As seen, the most critical risks or impediments in BIM integration corresponding to the highest eigenvector values were found to be R7 (Workflow transition difficulty), R3 (Difficulty in model management), R1 (Inadequate project experience) and R12 (Lack of BIM standard). Similarly, D10 (Efficient Contract Management), D9 (Efficient procurement management), D6 (Avoidance of Rework) and D8 (Effective Design Management) with higher eigenvector values were found to be highly affected drivers in the BIM integration context. On the other extreme, R9 (Increased short term workload), R5 (Inflexibility in management processes), R6 (Inadequate management commitments) and R10 (Rise in short term cost) with lower eigenvector centralities are the least critical impediments in BIM integration process. Similarly, D1(Effective collaboration), D2(Output/man hour), D3(On time completion) and D5(Within budget delivery) with lowest eigenvector values were found to be least influential drivers in the BIM integration process.

Table 2 Eigenvector Centralities of drivers and risks in 2-Mode network analysis

Drivers	Eigenvector Centrality	Risks impediments	Eigenvector Centrality
D10	0.418958	R7	0.447493
D9	0.403474	R3	0.378852
D6	0.372733	R1	0.352202
D8	0.318488	R12	0.325309
D4	0.305051	R8	0.313556
D7	0.280031	R4	0.305553
D5	0.278958	R13	0.254151
D3	0.276684	R2	0.243933
D2	0.250478	R11	0.210081
D1	0.180924	R10	0.161528
		R6	0.141054
		R5	0.104754
		R9	0.097354

Figure 2 depicts the association among the drivers in their relative stakes based on the bipartite analysis. As seen, among the drivers, D10 (Efficient contract management), D9 (Efficient procurement management) and D6 (Avoidance of rework) are the most affected drivers in the BIM integration in construction projects. Figure 3 shows the corresponding concentration of the drivers in terms of their impacts and influence in the BIM integration in construction projects.

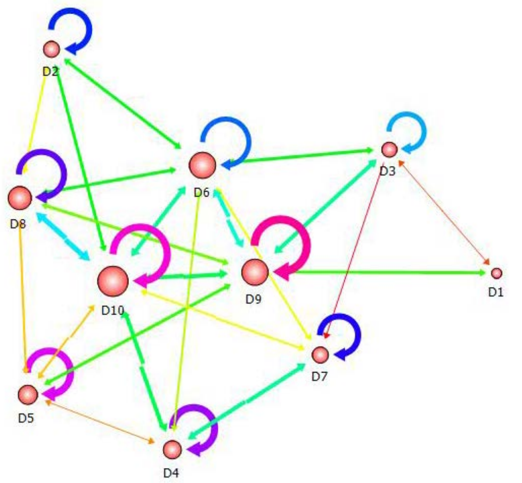

Figure 2. Relationships between drivers in Network Map

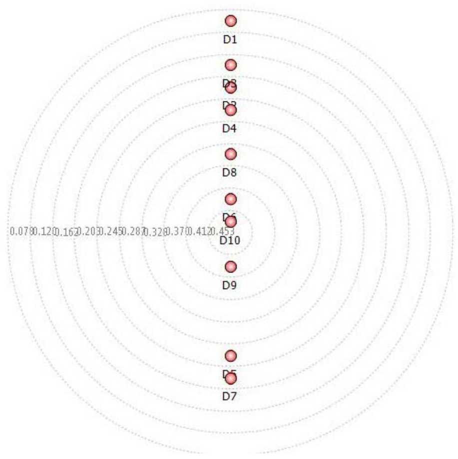

Figure 3. Concentric map of the drivers in Network Map

Figure 4 depicts the association among the impediments in their relative stakes based on the bipartite analysis. A seen, among the impediments, R7 (Efficient Contract Management), R3(Efficient procurement management) and R1(Avoidance of Rework) and R12(Workflow transition difficulty) are the most influencing risks in the BIM integration in construction projects. Notably, the degree of influence of these top order impediments on the drivers is exactly same as asserted by the 2-mode network analysis (with reference to Figure 1). Figure 5 shows the corresponding concentration of the impediments in terms of their impacts and influence within the project. Table 3 shows the corresponding eigenvector centralities of both drivers and the impediments in the bipartite analysis.

Table 3 Eigenvector Centralities of drivers and risks based on Bipartite Analysis

Drivers	Eigenvector Centrality	Risks impediments	Eigenvector Centrality
D10	0.494821	R7	0.511400
D9	0.425418	R3	0.406012
D6	0.411784	R1	0.391345
D8	0.349893	R12	0.322344
D5	0.265773	R4	0.303886
D4	0.263962	R8	0.271205
D7	0.22223	R2	0.242599
D2	0.217296	R13	0.213767
D3	0.197853	R11	0.177391
D1	0.078227	R10	0.106266
		R5	0.054323
		R6	0.020169
		R9	0.000000

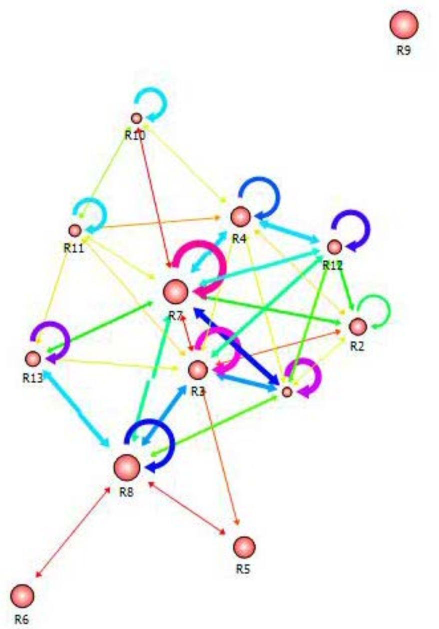

Figure 4. Relationships between the impediments in Network Map

Referring to the two key hypotheses, the above findings clearly support the assertions that indeed, the benefits of BIM integration are governed by multiple layers of interdependent driving factors associated with the stakeholders' networks based on their perceived understanding in construction projects. Higher centrality values particularly the eigenvector centrality values of the drivers or impediments clearly depict the degree of influence within the network structure. SNA model suggests that driving and impeding factors associated with BIM integration are interlinked and the influence of these factors on the project outcomes is mutually inclusive.

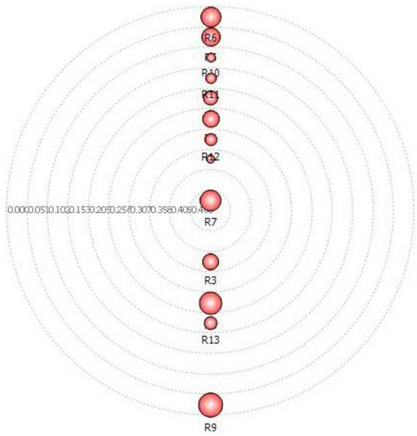

Figure 3. Concentric map of the impediments in Network Map

4.3.2 Cluster Analysis

In order to understand the clustering effects of both drivers and the impediments within the network structure, Cluster Analysis was performed. As depicted in Figure 4, there was only one cluster exist among the drivers. However, a total of 7 clusters were found among the impeding factors. Among these 7 clusters, the two biggest clusters were formed by the six risk instances, namely first cluster is between R6, R11 and R13 and the second cluster is between risks R2, R3 and R12. Two smaller clusters comprising only two risks instances were formed by R1 and R4 and R8 and R7 respectively. The remaining three risks namely R5, R9 and R10 formed the independent clusters on their own.

These results suggest how the combined effects of the risks instances can influence on the driving factors in collective terms. Such findings should provide a good basis for management in making decisions and managing risks in BIM integration context.

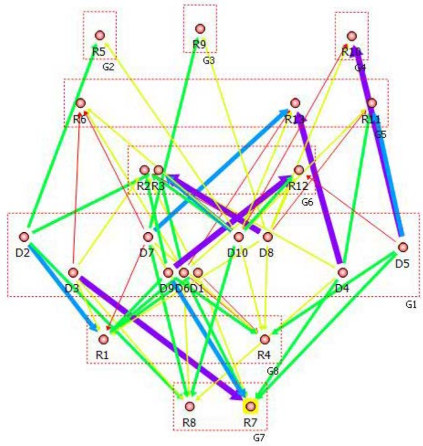

Figure 4. Clusters of impediments and drivers within the Network Structure

While the research has clearly demonstrated the methodological advancement particularly the SNA based methods in quantifying and managing impediments and achieving the desired outcomes by promoting the drivers in BIM integration in construction projects, the lack of empirical validation makes the findings somehow inconclusive. Thus the findings should be further analysed and reviewed based on primary empirical data in the industry context.

5 Conclusions

This research puts forward a new methodology for managing impediments and understanding the driving factors associated with BIM integration in construction project from a social network perspective. It has been postulated that ability for management of risks as impediments untruly lies with the interdependent networks of both risks and driving factors. Stakeholder's ability for management of a particular impediment and achieving the outcomes in BIM integration process depends on the centrality value and relative concentration of the respective factors within the problem domain and the network structure.

A total of 13 key risks as the impediments have been identified based on a past literature which was then investigated in association with 10 key driving factors involved in BIM integration in a typical construction project. Based on the literature review, secondary data were collected for estimating the probability and impact of these risks on the drivers in the BIM integration context. Social Network Analysis was performed using the Netminer 4.0 software package and underlying SNA measures were estimated. The findings suggest that higher centrality values depicts a stronger ability for managing and controlling the impediments which potentially allows devising appropriate strategies for managing the driving forces and optimising opportunities within the project. The methodological advancement of stakeholder's associated risk management solutions based on Social Network Analysis is expected to assist the decision makers dealing with the impediments and devising appropriate strategies for achieving the benefits upon BIM integration in construction projects.

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