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Research Article

An optimisation process to motivate effective adoption of BIM for refurbishment of complex buildings in New Zealand

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Abstract Despite the multidisciplinary networks involved in refurbishment of complex building projects, the lack of BIM adoption signifies lack of real BIM benefits towards acceptance of BIM within Architecture, Engineering and Construction (AEC).

To this end, this study empirically examines the potential real benefits between traditional network and BIM network for a real-time refurbishment case study project, through agent-based simulation modelling. A social network analysis theory is adapted to model the project interaction networks and a BIM prototype network. An assessment of the main stakeholders for BIM perception is carried out. We offered three prototype interaction networks for comparison of real BIM benefit.

An agent-based Bayesian network model is used to simulate the propagation of design error within the project networks. The result of the analysis show that BIM project diffuses error efficiently, while stakeholders recovers faster and nearly at the same time than traditional network. The optimised network shows better performance to the traditional network, when there is early involvement of subcontractors. The main contribution of this study is providing a novel approach to compare real benefits for traditional method to BIM method for refurbishment project and to provide avenue for project stakeholders to optimise their interaction through adoption of BIM.

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1. Introduction

The challenges towards adoption of Building Information Modelling (BIM) for refurbishment of complex building is starting to have considerable debate within the literature (Okakpu et al., 2018). However, one practical problem persistent to adoption of BIM is that most studies investigate within the limits of technical factors with a departure to social factors (Lee et al., 2013). Despite that adoption of innovation is fostered by cooperation among different participants (Barrett et al., 2007), this would make the analysis of project stakeholders more important to ascertain their perceptions about IT innovation. To encourage BIM adoption for refurbishment project, there is a need to examine refurbishment project stakeholders separate roles, responsibilities, relationships and interactions among themselves of which can be hampered by internal or external environmental factors (Liu et al., 2016).

Although BIM adoption environment requires a more multidisciplinary collaboration effort of different disciplines against information sharing, building design, construction techniques (Sebastian, 2011), the push might still be contingent upon restructuring of business processes and relationships, and some requirements could be outside of the current capacity and capability of either the technology or human resources (Rogers et al., 2015). It is also dependent upon the presence of participant firms that share compatible technologies, business processes, and cultures, led by people who hold attitudes and display behaviours conducive to collaboration (Brewer and Gajendran, 2012). Some of this aspect is inherited, for example through organisational culture, such that its effects are identified as a business process, technologies implemented or adopted and peoples' work practices (Okakpu et al., 2018). In addition, the construction industry is highly fragmented among the construction stakeholders, resulting to a high level of complexity of workflows due to a high number of companies participating on the same project and this increases the inefficiency of construction projects (Arayici et al., 2012). With these issues in mind, organisations can differ based on forms, functionalities, and the way they respond to changes. These forms or functionalities can be conventional standalone disciplines such as project implementation and facilities management, design, procurement, integrated professional services (IPS), executive, non-executive functions and services and other management innovations within a project delivery system. Therefore, these variables can be influenced based on their perceptions of information technology with the impact of internal and external factors.

Consequently, optimising organisational process to suit BIM adoption for refurbishment projects requires a thorough investigation on the entire project stakeholders and their interactions within the project. Even though, previous studies have centred on technical aspect of BIM (Arayici et al., 2011; Park and Kim, 2014; Sheth et al., 2010), Tulenheimo (2015) (Zheng et al., 2016) affirmed that technology adoption should involve technical and social activities. The present study examines the level of interaction for refurbishment project stakeholders in a traditional method and compare its level of benefit to a BIM prototype of refurbishment project stakeholder's interaction under the same environment. The study also carried out an optimisation process on the traditional method. To optimise the traditional method, the adopted case study project is subjected to Social Network Analysis (SNA) to model interactions and perceptions based on the role of project stakeholders, and consequently provide a virtual process of the prototype BIM interaction, for comparison of real benefits. The main objectives of the study are to answer the following research questions:

- What are the perceptions of refurbishment stakeholders on BIM adoption for refurbishment of multi-purpose building?
- What are the clear benefits between traditional method of refurbishment and BIM method?
- In what ways can the interaction of stakeholders be optimised to enhance a platform where BIM can be implemented?

A case study of a multipurpose building complex project in a tertiary institution in Auckland is adopted in this study to obtain the interaction of project networks during the refurbishment of the building project. This paper is structured as follows: the literature review about process optimisation, followed by the background for social network analysis and BIM. A description of case study and discussions on research findings of the empirical investigation follows. This will be followed by the result and discussion and then the conclusion follows.

2. Research background

2.1. Optimisation process

Construction project is seen to portray social interaction and project collaboration (Chinowsky et al., 2008). For the refurbishment project stakeholders, this social interaction can be isolated, and highly fragmented in nature in addition to procurement practices (Ali, 2014). It is also possible that the three common types of relationships in the construction firm (communication, information exchange, and knowledge exchange) are inefficient (Chinowsky et al., 2008; Pryke, 2004). One of the means to improve collaboration is through process optimisation. Although BIM can bring about collaboration, a lack of collaboration can influence how innovation is accepted in an organisation. Optimisation involves a way of structuring an organisation to accepting technology development among the refurbishment stakeholders. It is also the process of finding the most effective or favourable value or condition within a set of prioritised criteria or constraints by maximizing factors such as strength, reliability, communication, efficiency, including productivity among project stakeholders (Merrill et al., 2007). The refurbishment stakeholders are those actors that have an interest in a particular refurbishment project (Beringer et al., 2013). Accordingly, one characteristic of AEC industry is the unconventional nature of networks of stakeholder interaction which constitute building, refurbishment and construction projects (Linderoth, 2010). This has contributed to the challenges within projects including knowledge transfer in organisations and the diffusion of innovation propensity (Linderoth and Jacobsson, 2008). Therefore, the benefits of process optimisation can be achieved with stronger interaction of stakeholders in a project. However, with few studies around the adoption of BIM for refurbishment projects implies that there is little innovation diffusion and uncover of other factors such as optimisation to improve interaction of refurbishment stakeholders. A previous author suggested that there is a need to assess the actors of refurbishment, construction and building projects to enable adoption of BIM (Linderoth, 2010). The present research suggests improvement of social networks of entire refurbishment projects using social network analysis. In addition, this study examines interactions within and between teams of project stakeholders for refurbishment project according to their is necessary which involves assessing their roles, positions with Linkert values (Kelley, 2010), and connection with each other to determine the dynamics of healthy collaboration which would un arguably impact BIM adoption.

2.2. Social network theory and application

Social network analysis (SNA) is a method of investigating relationships among stakeholders especially when it concerns a specific interest or topic. This process helps to explore the conditions of social structures (Hu and Racherla, 2008). Many field of study such as sociologist, and scientist have been studying and applying the theory of SNA in diverse fields, which includes communication studies, information science, biology etc. to describe, visualize and statistical modelling (van Duijn and Vermunt, 2006), it is also used to study the natural mechanics occurring within (Li et al., 2011). SNA is proved to be an essential tool for assessing collaboration pattern of an organisation (Park et al., 2010).

The visual graphs implemented by this tool to map the networks consists of the nodes having metrics which describes the closeness, betweenness and degree centrality of actors, while the network has metrics as the density, modularity, average path length, and clustering. These metrics are used to translate complex visual analysis into quantitative values and can be used for interpretation of existing values, attitudes, and node features. Table 1 contains the definition as adapted from (Tichy et al., 1979) for some important metrics as used in the present research.

As many refurbishment project studies started gaining momentum to BIM adoption investigation, the lack of interest has been centred on slow innovation diffusion. Although, many research work focused on organisational collaboration in complex engineering tasks, SNA can also be applied in this venture (Xue et al., 2018). SNA is also employed in organisational behaviour studies (Easley and Kleinberg, 2010) and in construction management studies to investigate information flow between participants or project team and better integration of multi-disciplinary team (Alarcón et al., 2013).

2.3. Background of BIM and traditional way of refurbishment of complex building projects

It is very easy to think that BIM requires no definition however, it is surprising that BIM is very ambiguous based on different meanings as portrayed by different professionals. For example, based on empirical result of this study, for some people BIM is a software application, while some perceived it as a process for designing and documenting building information while as for other people, it is a new approach to practise to progressively implement new policies, contracts and relationships among project stakeholders. BIM can help stakeholders make effective decisions and carryout project with reduced costs, rework, schedules and better rework.

Traditional method is mainly concerned with 2D representation of information throughout all the entire project phase (Al Hattab and Hamzeh, 2013). The rate of collaboration in refurbishment project in a traditional settings is relatively small and is fraught with increase rework, cost and schedule overruns, and errors are bound to be present at each project interphase (Al Hattab and Hamzeh, 2015). For some authors, the traditional way is perceived to be most suitable for project with small size by the SMEs and hence do not make extra effort to invest in new technology and to reform their organisations in order to meet up with

Table 1 Social network quantitative metrics.

Type	Metric	Definition
Node	Closeness	This defines the shortest average length between nodes (Leonardi et al., 2013)
	Betweenness	This describes how many number of pairs of individuals are connected to a node (Fang et al., 2015)
	Degree of centrality	This describes the number of other nodes a node is connected to (Fang et al., 2015).
Network	Clustering	This describes how clustered group of individuals are compared (Xue et al., 2018)
	Average path length	Defines as the average step a node required to connect to each other (Alarcón et al., 2013)
	Density	This is the extent of how densely and cohesively the nodes are connected within a network (Hickethier et al., 2013)
	Modularity	The strength of the connections within a group of node compared to other group of node (Xue et al., 2018)

requirements of industry (Lam et al., 2017). Although, small projects have been proved to be much easier to adopt BIM compared to larger projects (Bryde et al., 2013), it offers much benefits through collaboration, error minimization and even early decision making (Okakpu et al., 2018). However, the benefits of BIM to traditional methods has been a concern for project stakeholders (Travaglini et al., 2014). Although BIM increases project collaboration, it should not be considered as just a software towards adoption but rather an effort of project stakeholders and their interactions. Hence, this will ensure a dynamic diffusion of BIM innovation for refurbishment project stakeholders.

3. Background instruction

In order to achieve the list of milestones mentioned earlier, this study proposes an optimised client organisational process to enable investigation of real BIM benefits for refurbishment project stakeholders who are planning to adopt BIM. To understand the effectiveness of BIM adoption in this venture, we adopted a case study refurbishment project. The refurbishment case study project is a multi-purpose building facility in a tertiary institution in Auckland. This project was selected based on the difficulties and challenges during its execution. Although, the project was fast tracked, there were many loses and uncertainties during the project execution. We adopted a snowball technique to identify the refurbishment stakeholders involved in the project case study. We administered a quantitative interview to assess the collaboration and consequently the BIM perception. A social network analysis software is used to model the interaction of the case study project stakeholder's "A". A virtual network of interaction of the stakeholders is modelled with BIM and named "B". The two networks are compared based on the real benefits. This is followed by optimising the traditional method to yield "C". The three models are also compared for real benefits using agent-based modelling simulation for error propagation. Thereafter, conclusion was drawn including the limitation of the study. The methodological flowchart for the study is shown in Fig. 1. Fig. 1 demonstrates the steps, methods and outcomes for each level of the research. It can be noted that "A" denotes the traditional method, "B" denotes the BIM method, while "C" denotes the networks that have improved collaboration or edges known as optimised network in this study.

3.1. Experimental design

The aim of the experiment is to assess the interaction of project stakeholders using social network theory and to compare with the virtual BIM interaction of the project stakeholders. The idea is to test the environmental factors that impact on stakeholder's decisions and as well as the interaction (information flow) of project stakeholders in the given project. The project stakeholders were identified through a snowball technique. Table 2 shows the demography of the project stakeholders.

Although SNA views the relationships between project stakeholders as a multi-layered independent network structure, in this study, it will be used to visualise the collaboration in the case study project coalition with Gephi software and to provide quantitative metrics. And as well

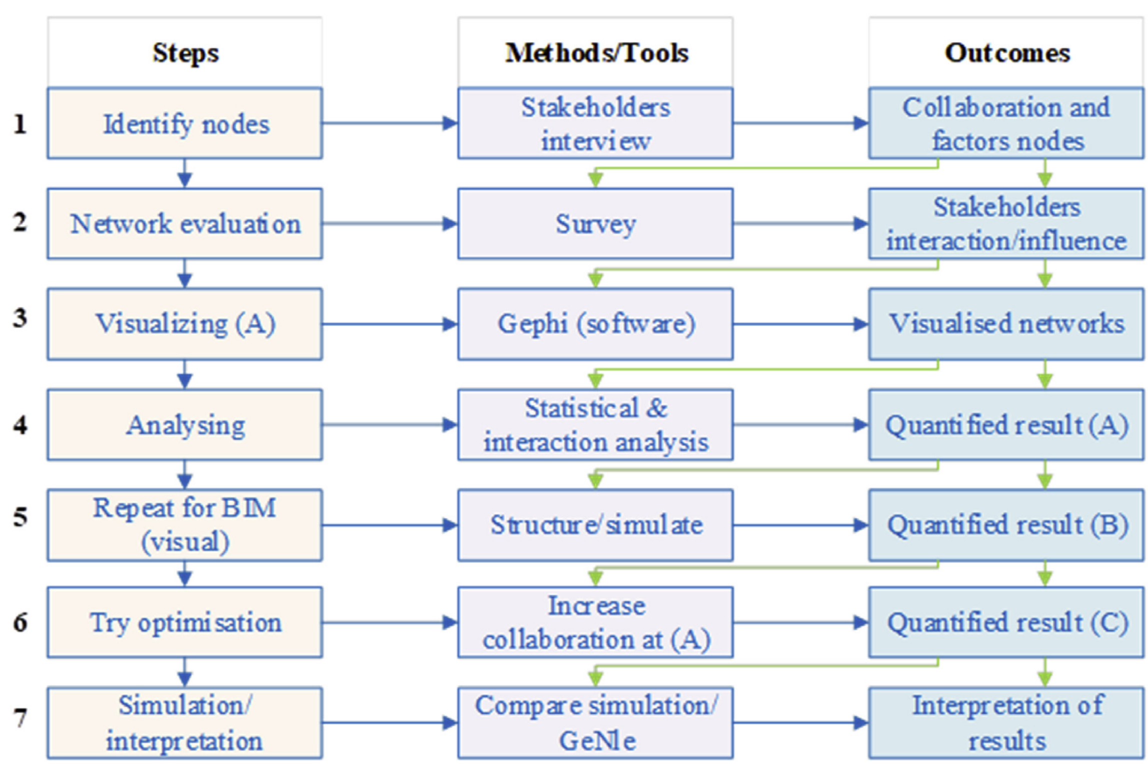


Fig. 1 Methodology flow chart.

Table 2 The demography of the project stakeholders involved in the case study project.

Main stakeholders	Organisations	Number in the group
Project manager	1	1
main contractor	1	1
Architect	1	3
Sub-contractor1 F.S	7	Minimum of 4
Prin consult Mech	1	3
space manager (client)	1	6
space coordinator	1	1
Value manager	1	1
Prin consult Elect	1	3
Cost estimator	1	1
Space planner	1	1
Supplier	1	4
IT man	1	4
Client representative	1	1

to assess how environmental factors impacted on their role in the project. The result would be used to assess the nudge to adopt innovation.

3.2. Case study

A case study design was chosen in line with the aim to investigate optimisation process through a network of relationships in a refurbishment project. In this context, a collaboration-based questionnaire is needed. The main environmental factors that impact refurbishment project stakeholders are adopted to assess the project stakeholder's role. The study is focused on a completed refurbishment project of tertiary institution in Auckland. The project is initially executed without BIM. Because of the complexity of the refurbishment process, we examined the effect of introduction of BIM (virtual process) and compared with the conventional process for real time benefit. We will then propose an optimised process to increase benefits from the current process.

3.3. Refurbishment project background

The selected case project (Fig. 2a and b) is a multipurpose commercial complex building situated in Auckland. This building is used for academic and administration offices, student classrooms, and lecture spaces. A multipurpose building has many characteristics such as large-scale, functional cooperation, multi-functions. It involved multiple participants. Therefore, the case study project has a wide range of stakeholders whom we abstracted as the network nodes in this study. We considered a collaborative relationship to analyse the density and centrality of the refurbishment process. This is because effective collaboration can be hampered between individuals with different roles or priorities in the project. Overall, the project was proposed to last for 3 months between November 2016 to January 2017. It however lasted for 5 months. The total cost of the project is approximately $5 Million. However, because of the short time stipulated to the project, the budget as well as the project was fragmented into having different level of the storey refurbishment at different project time. This resulted to interdependence and newness of functions and the different stakeholders involved ranging from client organisation, designer/Architect, general contractor, subcontractors, consultants, suppliers, house managers, project manager, client representatives, IT, etc.

The project manager coordinates the contract awards to the externals. The main contractors coordinate the subcontractors, material supplies and equipment. Fig. 3 shows the organisational chart.

4. Data collection

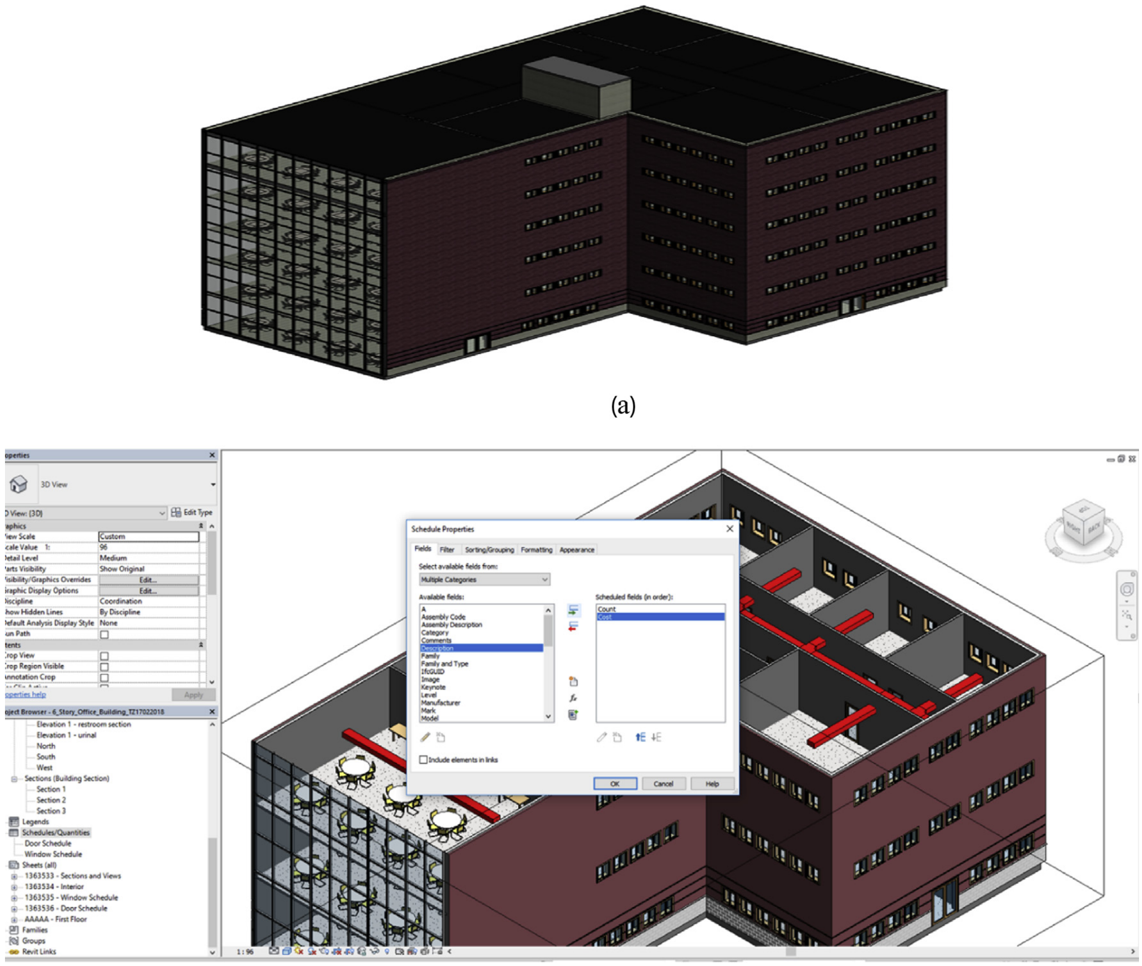
The project stakeholders or actors are considered important in refurbishment project when dealing with relationship network. These actors are the nodes in the present network model. The actors have been coded due to ethics and privacy. In the analysis of the social network, the ties indicate the communication between the individuals within the process of the project execution. The data where administered using a paper-based questionnaire distributed to individuals involved in the completed refurbishment project. The innovative network of this project is analysed by the collaborative event that occurred between the project stakeholders. The most important role in the project is identified through the interaction process. Although, the project organisation can be seen as a combination of social groups with a defined pattern of interaction over time, this constitutes difficulties for SNA data collection (Zheng et al., 2016). The nature of the interview was a collaboration questionnaire designed to extract the intensity of interaction among the project stakeholders. For example, the project stakeholders can be asked to list the number of stakeholders they interacted during the project and how often they interacted with each other. The rate of interaction can be measured with "frequent", "less frequent", and "none".

In addition, a structured questionnaire is more suitable to determine the relationship between variables and the statistical processing of data. Hence, the map network assumed to be quantitative data. While the main stakeholders were assessed for BIM perception for the refurbishment project using environmental impact factors, a collaboration questionnaire identifies the level of interaction and the most important actors involved in the project interaction for the entire project duration.

5. Results and discussion

5.1. The completed relationship networks

We adopted the main environmental factors suggested by (Okakpu et al., 2019) from an empirical and validated study which forms part of this study for assessment on the project stakeholders. We only assessed the main stakeholders to determine their BIM perceptions. Overall, the entire network interaction was analysed to show the connections



(a)

(b)

Fig. 2 (a) 3D view of the existing building (case study adopted: Auckland tertiary institution Auckland). (b) Case study (adapted: 3D view, multipurpose existing building model for Auckland tertiary institution).

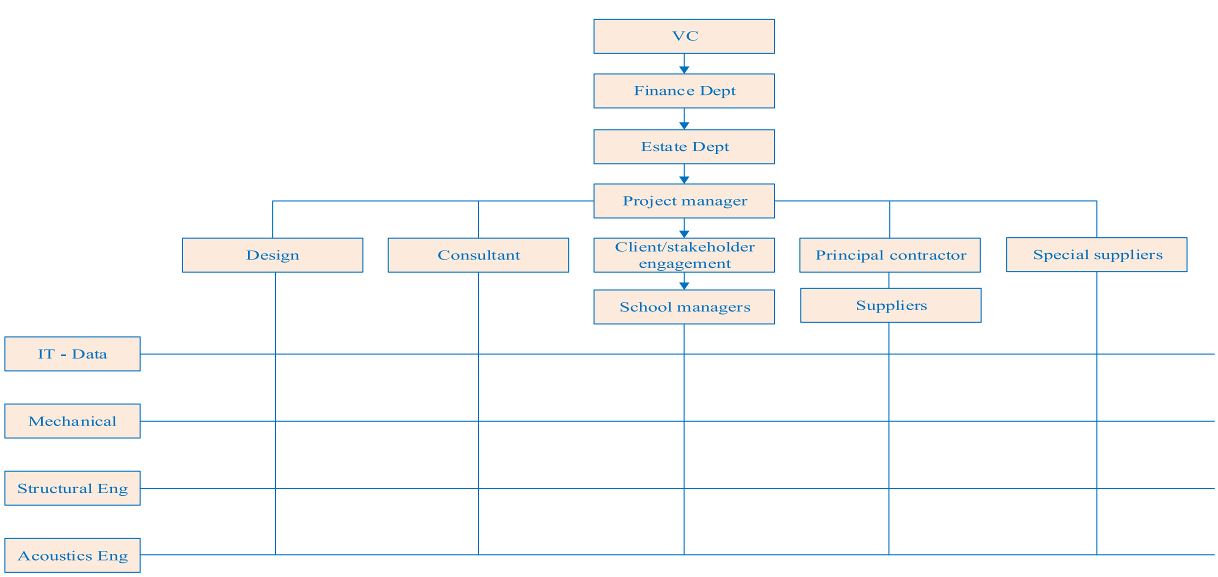


Fig. 3 The formal organisational structure of the case project.

and level of communication among the project stakeholders. From the network, the case study project is highly fragmented, as each different team in the project collaborate closely at the expense of other team. This is as a result of poor information exchange and transparency, leading to poor project value and lack of awareness. Fig. 4 shows the traditional network structure and its virtual BIM network structure. It also shows the actors presented as the network nodes.

In this case study, it can be seen from the traditional network that there are 12 groups all having heads and links to represent existing interaction pattern and information exchange. Therefore, the groups work separately and closely. In the traditional network, the information revolves around the main clients and hardly go towards the subcontractors. The main contractor bears the central role in the project. This can be seen where the main contractor has the highest connection. While on the BIM virtual network, all the participants are connected, and this allows the integration of any change at the early stage.

5.2. Case study: assessment of main project stakeholders BIM perception using a five linkert scale

We conducted a BIM adoption assessment on the main actors to understand how their BIM perceptions impact their decision to adopt BIM using the main environmental factors that influence BIM adoption for refurbishment project in New Zealand construction industry (Okakpu et al., 2019). The assessment of project stakeholders is necessary in order to determine where there is less BIM perceptions and collaborative environment (Abdirad and Pishdad-Bozorgi, 2014). The assessment model uses a five-point Linkert-scale. For example, the stakeholders were asked to indicate from 1 to 5 how such factors impact their decisions to adopt BIM for the refurbishment case study project, where 1 indicates no impact, while 5 indicates very strong impact. The result of the assessment shows that standards and culture of organisation generally impacts refurbishment stakeholder's decision to adopt BIM. It further shows that with the current traditional networks, the sub-contractors are not involved in the decision making and therefore contributed no effort to adoption of BIM. Fig. 5 is the adapted validated assessment model from previous empirical study which also forms part of the current study.

Fig. 6 shows the perceptions of the refurbishment project stakeholders regarding the environmental factors and its impact towards the decision to adopt BIM. We can deduct from the figure above that culture of organisation highly impacted the stakeholders. For example, culture of organisation mostly impacted on the main contractor's role in the project. While project manager including the cost-estimator perceives standard as the main impact factors for their BIM decisions, space-users are mainly impacted by culture of organisation and the information sharing. Therefore, the environmental assessment indicates how much need to address these environmental factors for a successful BIM adoption for those refurbishment project owned by client organisation. Hence, based on Fig. 6, we identified the main stakeholder with lowest BIM perceptions in the case study project namely sub-contractors, space coordinator, and IT technician and thus, their positions can be optimised for real time benefits.

5.3. The social network structures

The results of the network structures were calculated with Gephi software and hence summarised in Table 3. Hence, Table 3 shows the metrics for the traditional network (A) versus the BIM virtual network (B).

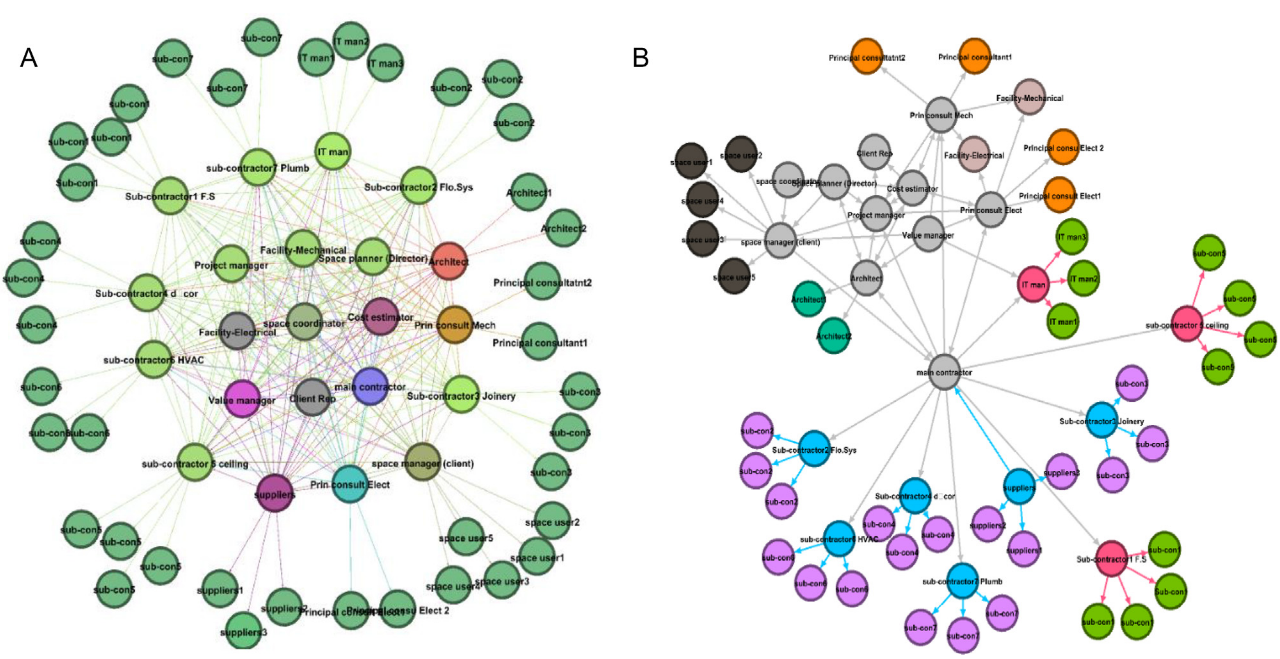


Fig. 4 The BIM virtual network (a) and Traditional network (b).

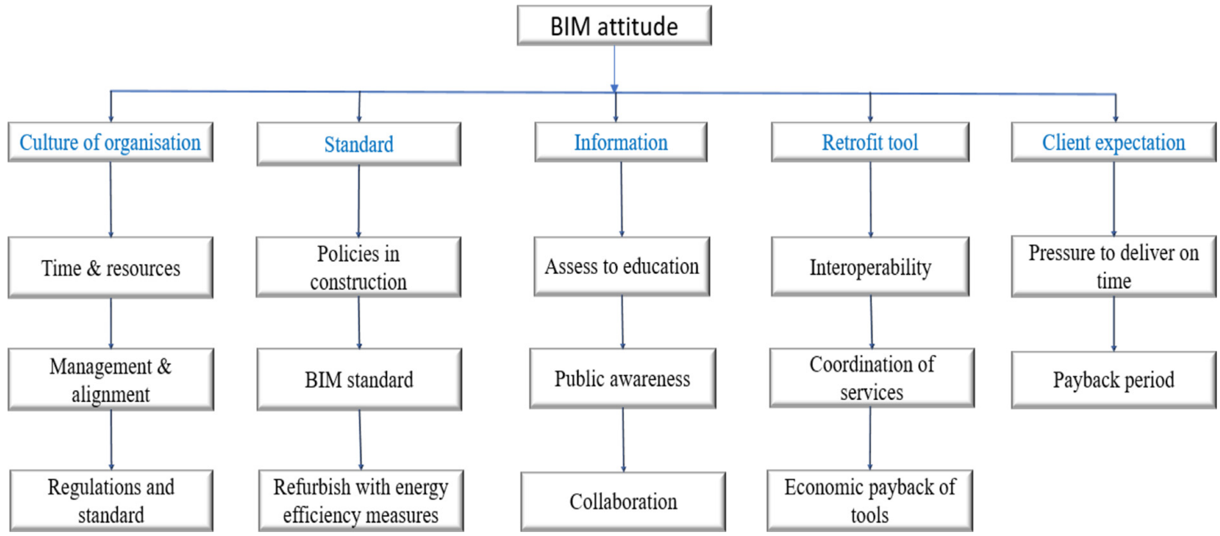


Fig. 5 The environmental factors that impact BIM adoption decision for refurbishment project adopted from (Okakpu et al., 2019).

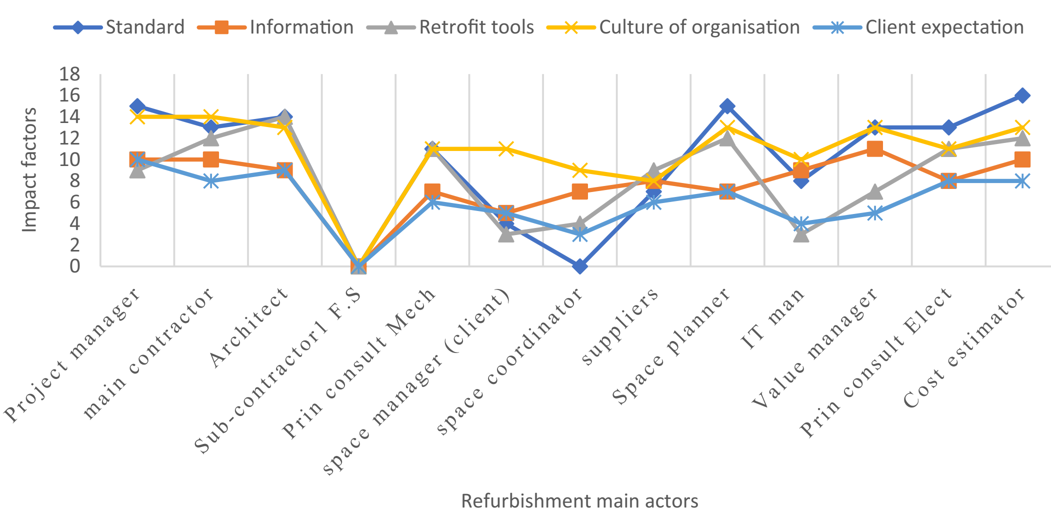


Fig. 6 The result of the BIM adoption assessment on a case study in Auckland.

For the structure metrics, the graph type is undirected for each of the networks as the information can happen both ways. Considering the traditional structure, there are less interaction between the nodes (actors). There seems to be a restriction of communication between the clients and the sub-contractors. These shows lack of involvement of some of the project actors at the conceptual stage of the refurbishment project. However, the number of edges is higher in BIM virtual interaction compared to the traditional (existing) network as there is more collaboration and teamwork exist between the project stakeholders as opposed by the traditional network. Therefore, on average, the degree of centrality and betweenness for the two networks (traditional and BIM) is 2.345 and 38, and 8.484 and 34 respectively. This indicates that refurbishment project with BIM has more connections with higher collaboration and the actors can easily reach out within their network. The closeness values are 3.287 and 2.267 for

Table 3 The comparison of traditional network (A) vs the BIM network (B).

Type	Metric	Network A	Network B
Structure	Number of nodes	62	62
	Graph type	undirected	undirected
	Number of edges	73	263
Node	Degree centrality	2.345	8.484
	Closeness	3.287	2.267
	Betweenness	38	35
Network	Density	0.039	0.139
	Number of groups	13	13
	Modularity	0.642	0.125
	Avg. clustering coefficient	0.159	0.827
	Average path length	3.408	2.267
	Diameter	5	4

traditional and BIM network respectively. It can be noted that the higher the value of closeness, the higher the edges are required to connect with the nodes. The path length and modularity values for traditional and BIM were 3.408 and 0.642, and 2.267 and 0.125 respectively. From the result, traditional networks are shown to have higher values compare to BIM networks. This can be explained that the higher the path length and modularity the more edges are required to connect to each other, and this is significant in the traditional network as shown in Fig. 4. The BIM network structure has a higher value on density, average clustering coefficient, compared to the traditional structure. This can be explained by higher number of connections between the main project stakeholders from each group in the BIM network structure. The diameter of the two structures is found to be same.

5.4. Optimisation process

The values obtained from the traditional network (A), and BIM virtual network (B), is considered to propose an optimised network termed (C). Although, the concept of partnering a variety of practices is assumed to facilitate greater collaboration among the project stakeholders (Barlow et al., 1997). Hence, we considered the traditional network as the minimum values (A) while BIM network (B) has the maximum value. We recalled that in construction industry, stakeholders' interaction may be short term and project oriented or long-term and project oriented (Barlow and Jashapara, 1998). This means that short term interaction is likely to depend on project governance issues to secure immediate project benefits rather than developing advanced collaboration, while a long-term interaction involves optimising the stakeholders' interaction through a closer collaboration in order to maximise benefits on a long-term (Beach et al., 2005). In addition, we examined the result between network A and Network B. We found that there is a significant difference at the edges where network A has 73 edges and network B has 263 edges. We determine a new network by increasing the collaboration (number of edges) by using optimisation (MaxValue) to extrapolate an acceptable value which offers increased collaboration. Although, the density of the network describes the interactions and connectivity of the actors (nodes) (Pryke, 2004), it has been regarded as the best indicator for network's connectivity as shown in Equation (1) where l is the number of existent lines/edges/connection, n represents the number of nodes.

$$Density = \frac{\frac{l}{n*(n-1)}}{2} \tag{1}$$

$$Maximum\ number\ of\ edges\,(PC) = n*\frac{(n-1)}{2} \tag{2}$$

Therefore, from the Equations (1) and (2) we deduced that density of the network is related to the potential number of connections and the actual connections (Equation (3))

$$Network\ density = \frac{actual\ connections}{potential\ connections} \tag{3}$$

From the experiment based on the traditional network using Gephi, it can be deduced that there are increase in the values of average path length. In network 1 we increased collaboration between the project manager and the subcontractors. While in network 2 there is an increase in interaction around the **clients,** while in network 3 considered both increase interaction at the **sub-contractors** and the **user groups**. Therefore, the networks show higher performance compared to the traditional network but lower to the BIM method. Table 4 shows the values of the metrics for the generated networks. Fig. 7 shows the comparison of the five different networks.

From Fig. 8, we see that though the networks have the same number of nodes, the number of edges marks a distinction between the networks. The average part lengths for the traditional network is higher compared to BIM network. The networks generated as network C (Table 5) shows relatively lower average part lengths. This shows that the smaller the average part length the closer the stakeholders to collaborate with each other in the project. Network 3 has the lowest average part length, and this network involves collaboration with the sub-contractors at the early design phase of the refurbishment project.

5.5. Experiment 2: design error diffusion simulation in the case study project network

The main aim of this experiment is to overcome the limitations of Gephi which lacks the ability to determine which of the networks enhances error diffusion and ability to recover on timely. However, Bayesian network model using GeNIe software supports the dynamic simulation of the network. It also shows how individual stakeholders (agents) respond to uncertainties based on the project network. In this experiment, an agent-based model was prepared to examine how error could diffuse through the various network's structures modelled (traditional to BIM network). In this experiment, we adopted the Bayesian network model for diagnoses and management of liver disorder using an approach on Hepar II. The world "agents" is the stakeholders with ties or linkages (Fig. 9). These agents can be asked to have an opinion or act according to a behavioural circumstance. For example, the introduction of error into a model will allow the agents to respond based on the nature of ties they have with each other.

5.5.1. The application of bayesian network using hepar II model

The Bayesian network are acyclic directed graphs modelling probabilistic dependencies and independencies among

Table 4 Actual number of connections for the optimised networks from Gephi.

Network	Density	Potential connection	Actual connections
Network 1	0.06	1891	114
Network 2	0.043	1891	82
Network 3	0.044	1891	84

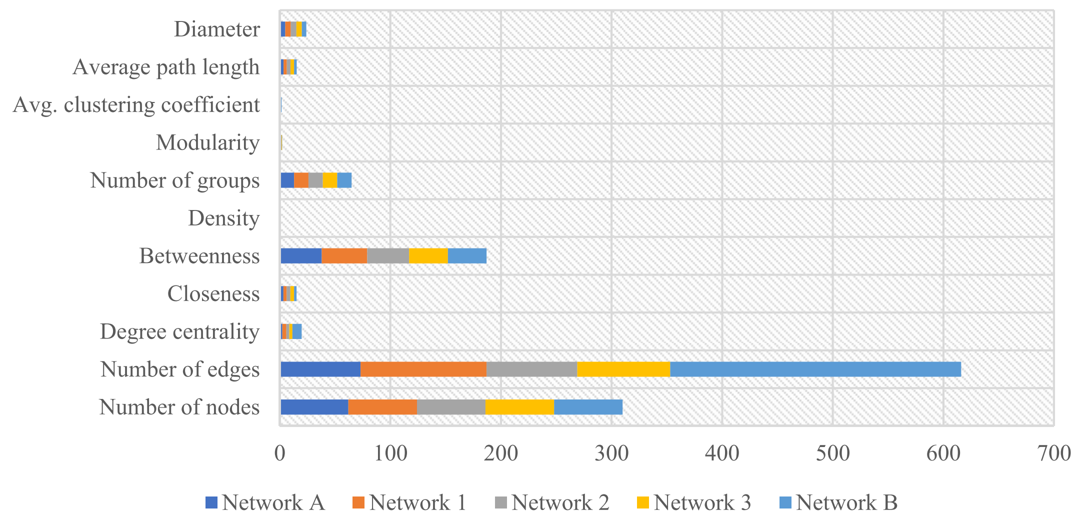


Fig. 7 The five different refurbishment project network comparisons.

variables. In this study, the dependencies and independencies occur between nodes or also called the project stakeholders or agents as per in Bayesian network. The graphical part of Bayesian network shows the structure of interaction among the project stakeholders and these are quantified by conditional probability distributions (Seixas et al., 2014). In order to adapt Hepar II, we considered the effects of the level of complexities of the networks from Gephi but less consideration to the level of initial error break-out. Hence, the disorders are considered as the error introduced into the network and are allowed to simulate through the network as designed error. The time to identify the error, error percentage, recovery chance is measured by each node in the network. The nodes are set as observers with a defined probability of occurrence of 0.3%, 0.3% and 0.4% respectively. The error and where it will occur is set as the target while other nodes observed the effects. Five different networks were modelled as per previously in Gephi. The first network (A) is the traditional network. The last network is the BIM network while the three other networks are the optimised generated network as derived from Gephi. Figs. 8 and 9 shows a sample model and the target menu box for the simulation. Note that the question mark in Fig. 8 indicates that simulation of error has not been initiated. Carrying out different iteration for the initial error outbreak was insignificant for all the five networks as the results clearly shows the same values. The results obtained were mainly based on the complexities of the project network (Figs. 10—14).

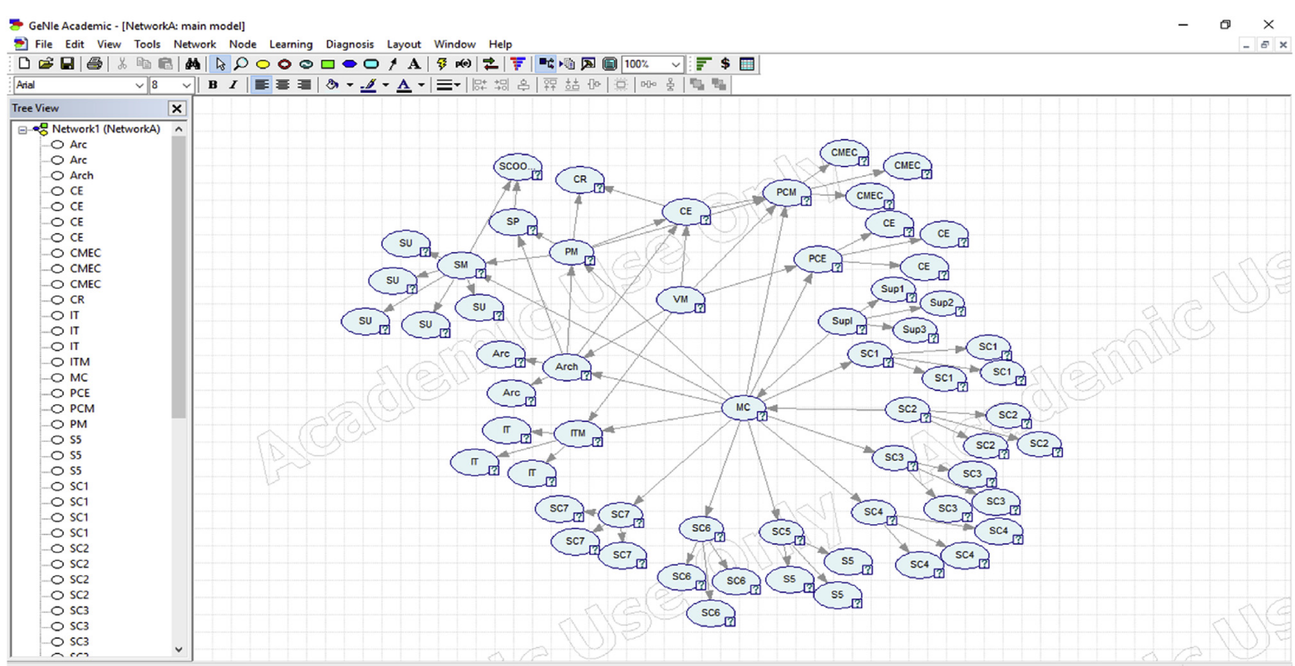


Fig. 8 Sample of a Bayesian network (agent-model) for the traditional network structure interface.

Table 5 Values of the metrics generated from SNA for network C.

Type	Metric	Network 1	Network 2	Network 3
Structure	Number of nodes	62	62	62
	Graph type	undirected	undirected	undirected
	Number of edges	114	82	84
Node	Degree centrality	3.677	2.645	2.71
	Closeness	3.006	3.337	3.263
	Betweenness	41	38	35
Network	Density	0.06	0.043	0.044
	Number of groups	13	13	13
	Modularity	0.354	0.565	0.527
	Avg. clustering coefficient	0.365	0.135	0.189
	Average path length	3.006	3.337	3.263
	Diameter	5	5	5

Table 6 shows the parameters considered in the experiment. Three different combination where performed on each network structures giving a total of six iteration. For all the iterations, an initial error percent, initial time to identify error and recovery chance for the target node where established at the architect's node.

The examination was viewed by checking through the time to identify error, error percentage and recovery-chance over the established phenomenon. The various iterations for the five networks are compared as shown in the graphs.

For each of the scenario, we plotted graphs to represent the different interactions for the five networks. In addition, each of the iterations shows different sources of errors and different diffusion parts. The results show the amount of errors perceived by main stakeholders, lent of time to identify the design error and the ability to recover and resolve the problem identified to avoid further design error. These are compared over the entire networks. The result also demonstrates the time (in weeks) it takes the entire project stakeholders in the network to identify the error as well as to make design changes as required. The plots indicate the overall diffusion of errors and recovery within all the networks (Fig. 15).

The result indicates that it takes more time for error diffusion on traditional network compared to the BIM network. Considering the three scenarios for the optimised network, the three network shows faster network diffusion compared to the original network (A). The three new network shows differences at the time for error diffusion and the time to recover or gaining resistance. The BIM network also shows higher recovery and resistance and shows that these errors spreads and dies out quickly while the stakeholders recover from such errors. It can be noted

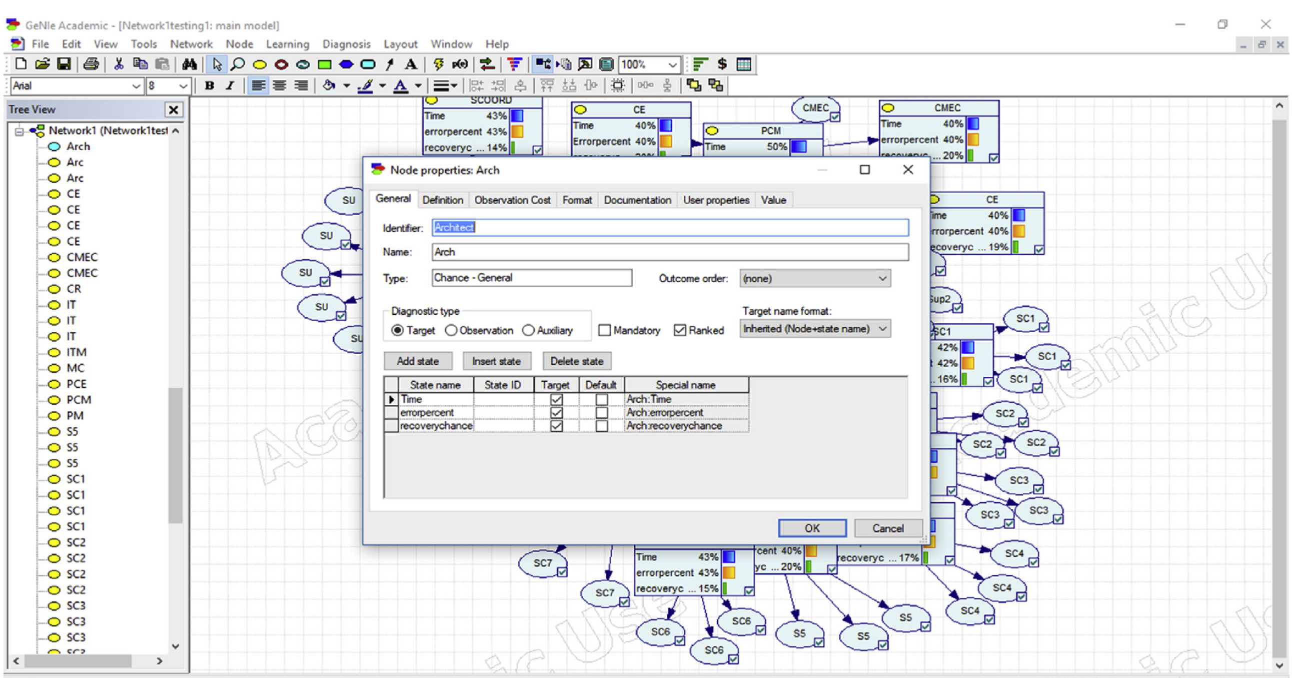


Fig. 9 Parameter drop down menu for target, observation and auxiliary nodes.

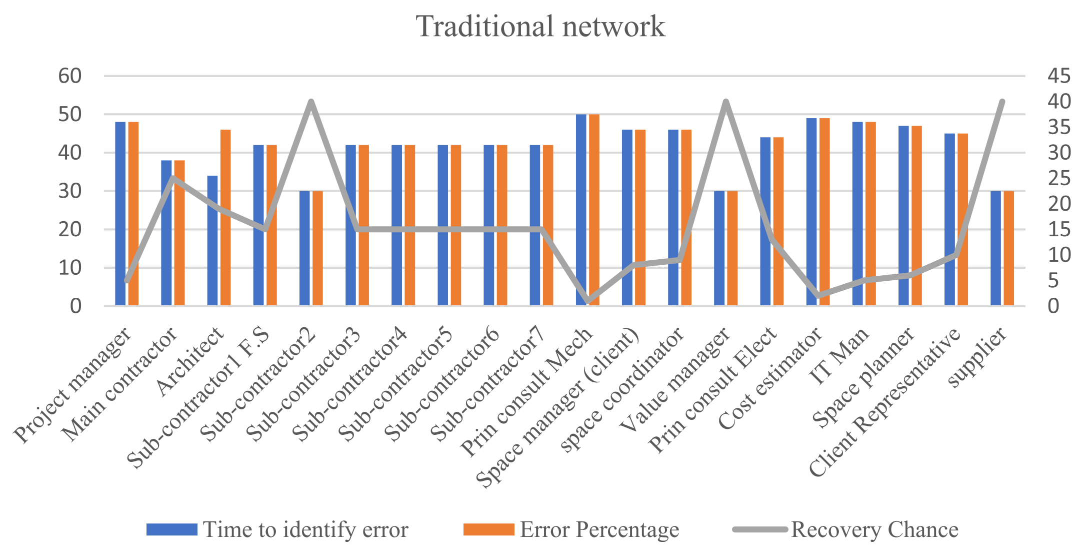


Fig. 10 Simulation result for the main traditional network.

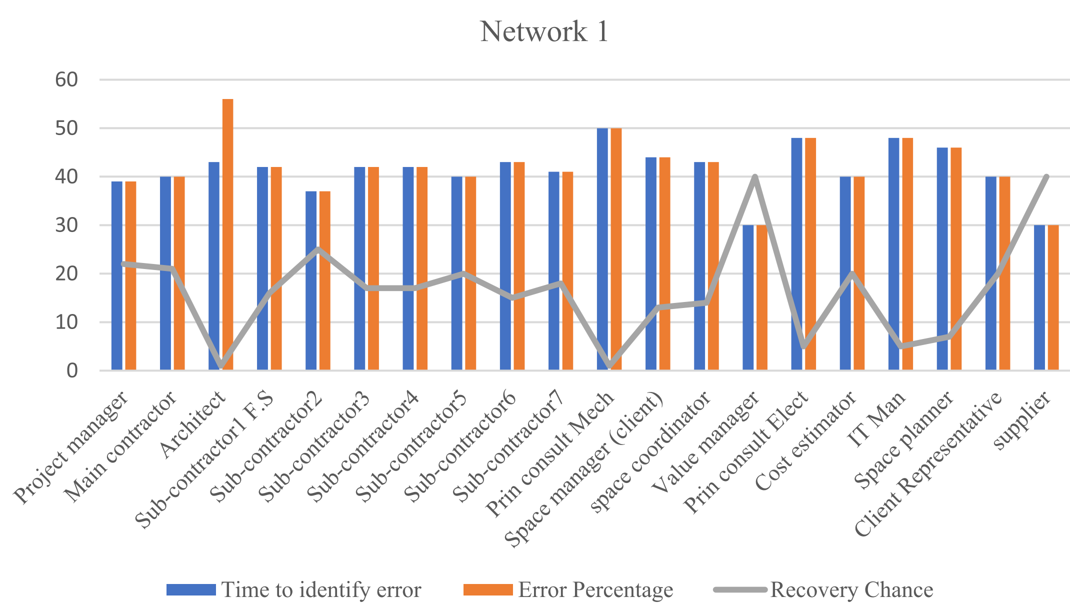


Fig. 11 Simulation result for error propagation on optimised network involving project manager and subcontractor.

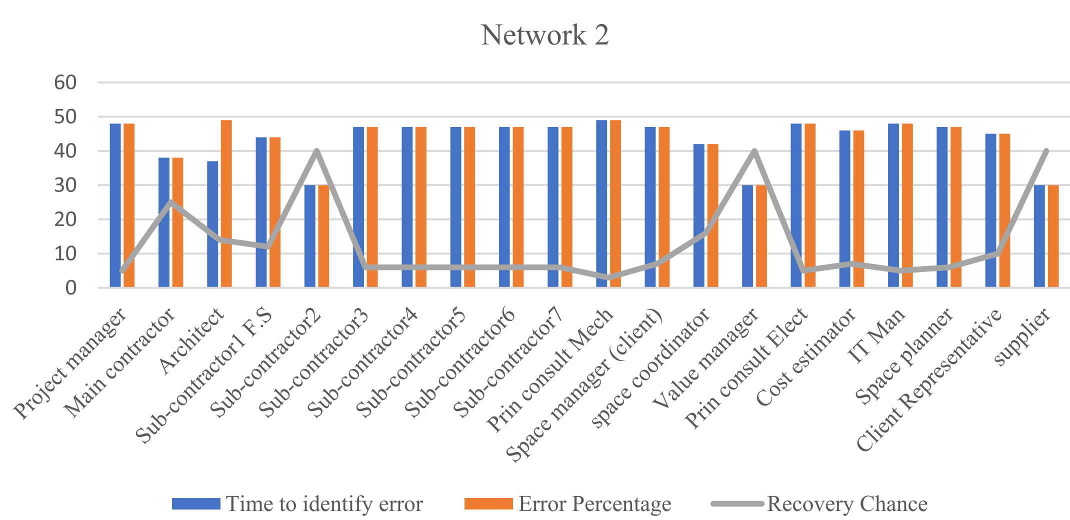


Fig. 12 Simulation result for error propagation on optimised network involving clients.

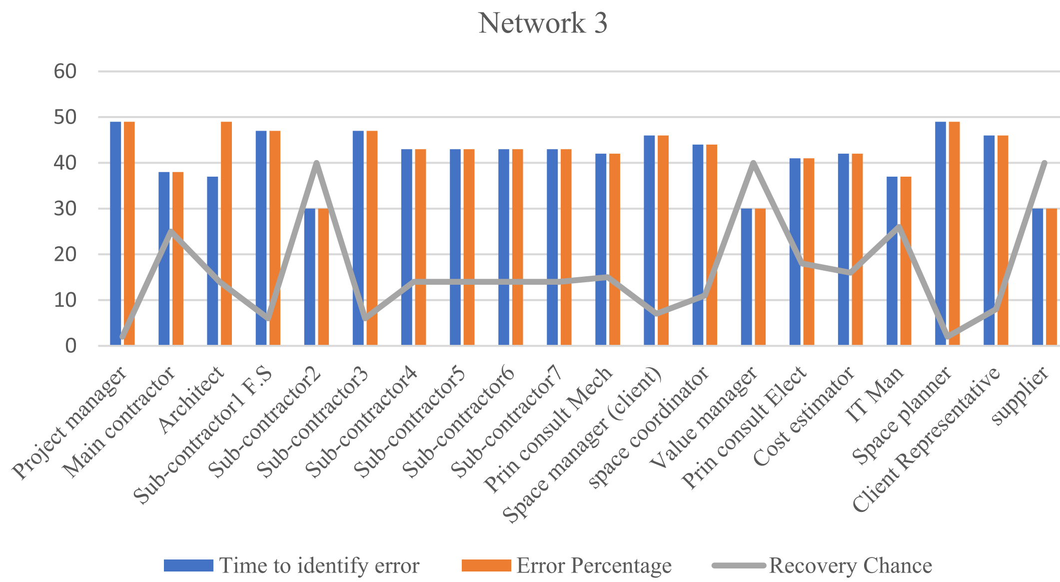


Fig. 13 Simulation result for error propagation on optimised network involving subcontractors and IT man.

from the plots that all the network resist and regain from the design error, however, the differences are based on the time required to recover from the error demonstrated as percentage recovery. Although, the BIM network recovered 100%, because there might be deficiencies due to human errors, hence, we should not expect the recovery to be 100% efficient in real world. The 100% occurred due to the higher level of interaction such as the improved collaboration among the project stakeholders to indicate the benefit of BIM for the refurbishment project. Other networks showed lesser performance due to less collaboration or interaction linkage within the project network.

The implication of the optimised network is that the three-network presented offers any construction organisation to consider the best strategy to improve collaboration in their refurbishment projects. It also shows the importance of some roles regarding project coordination and the importance of adopting BIM which offers an improved collaboration. For instance, the improvement of collaboration among the main stakeholders such as the subcontractors increased the performance of the project. This is in line with (Barlow et al., 1997) who suggested that improving the relationship for subcontractors and suppliers in projects can offer cost and quality savings. Even though most organisations are sceptical to adopt BIM for refurbishment projects, the benefits of BIM can be realised through closer relationship with different main stakeholders such as the subcontractors and the suppliers.

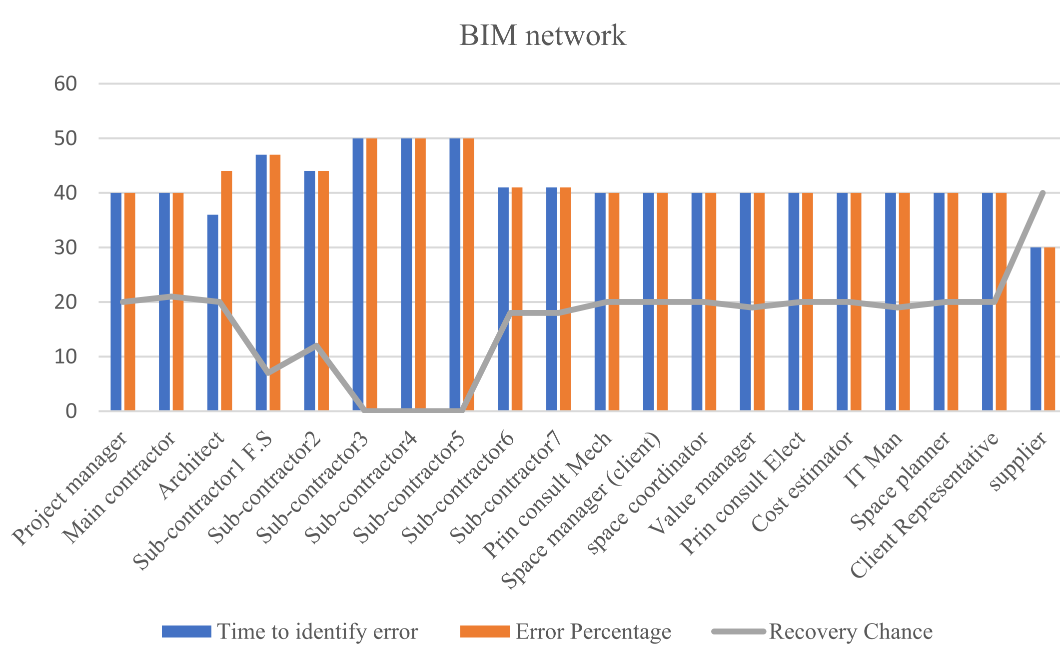


Fig. 14 Simulation result for error propagation on BIM network.

Table 6 The parametric used by Genie.

Parameter	Definition	Applied values
Target node	Number of individuals generating design error	Percentage of individuals
Observation node	Frequency of design error checks to identify errors	Number of weeks
Time	Time to identify error	Final percentage
Error percent	The quantity of error perceived by each node	Number of percentage increase
Recovery chance	Probability of an individual not continue to do error	Number of percentage increase

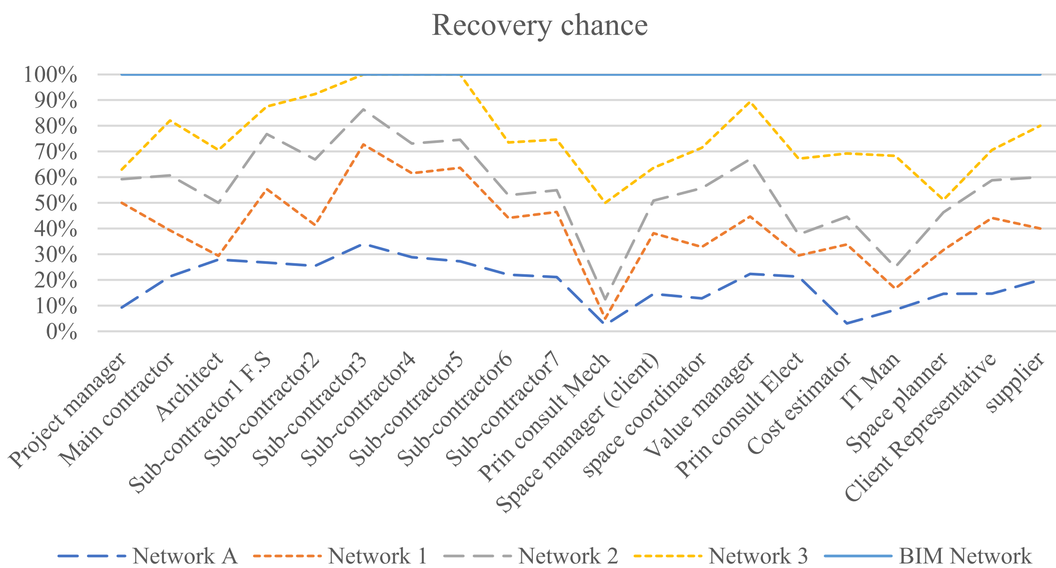


Fig. 15 The overall recovery chance for each network.

Clearly, the advantage of optimised project network in this study offers a stronger collaborative partnership in which the organisations would work in a more cooperative manner. These networks are seen to perform better than the traditional method used by the project stakeholders for the case study and hence entails that client organisation should re-address the business processes to improve the exchange of information, including cooperative relationship while building collaboration mechanisms. Therefore, this paper covers the gap identified by (Okakpu et al., 2018) for optimisation process to adopt BIM for refurbishment project.

6. Conclusions

This paper presents the real benefits of adopting BIM for refurbishment projects to counteract the current reactive traditional measures that are ineffective in reducing the effects of uncertainties that occur in refurbishment projects. A case study refurbishment project is adopted from an Auckland tertiary institution. The case study provides the avenue to examine the refurbishment project stakeholders and their interaction within the project. A social network theory approach is adopted to analyse the traditional method of refurbishment and the virtual BIM method based on the project interaction. An environmental impact assessment is carried out on the main stakeholders BIM perception. Specifically, by comprehensively assessing and quantifying the contextual BIM impacts on the main project stakeholders, three main project stakeholders are proposed to improve their project interaction namely; the IT technician, the space coordinator and the sub-contractors as a result of their low BIM perception which invariably determines their low interaction in the case study project. Using Gephi to model the two networks (traditional and BIM network) and additional 3 project networks based on the proposed 3 main project stakeholders improvement interaction, and with consideration to the theoretical assumptions, the resulting metrics shows that using BIM improves the coordination and information exchange within the project compared to the traditional network.

The improved links or edges within the optimised network created a stronger social network with increased collaboration between the project team members. Furthermore, agent-based modelling was employed to simulate the propagation of error in the five different networks using a Bayesian network model with consideration to Haper II for complex networks. The result portrays that BIM network model was almost hundred percent effective in reducing errors or project uncertainties. Therefore, the implementation of information exchange, clash detection and collaboration offered by BIM use could be the main reason for quick recovery from uncertainties within the project. The traditional method shows very low recovery mechanism from the project uncertainties and hence, would have many challenges and risks for a building refurbishment. Other three network showed a better recovery time than the traditional method network 1 (project manager and subcontractors), network 2 (client or space coordinator), and network 3 (subcontractors and IT technicians). Among the three optimised networks, improving collaboration across the subcontractors with IT man significantly improved the performance of the project network (network 3). It is worthy to note that although the links in this network is smaller than other optimised network such as network 3, the error was introduced at the architect domain and the architects has a direct effect to IT technician. This confirms why subcontractors should be adequately involved during the early phase of the project. It also significantly shows that project dependent on IT innovation can be cheap to meet the required project performance. This study considered a real case study in order to compare the real benefit of BIM adoption for refurbishment project and by the traditional technique. The study shows that refurbishment project with BIM implementation can minimise error with adequate error identification time.

As future work, we intend to investigate the sensitivity analysis of each network and as well invite experts or focus group to comment on the relevance of the five different Gephi network and Bayesian network simulations towards BIM collaboration, error management and recovery time for project stakeholders real time benefits. The limitation of this study is that only design error introduced at the architect domain was examined. Further studies should investigate error propagation by setting targets on different parts of the project network through the main refurbishment project stakeholders.

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