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# Collaboration in BIM-based construction networks: a qualitative model of influential factors

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Engineering, Construction and Architectural Management


## Abstract

Purpose – The purpose of this paper is to present a modified model for collaboration in BIM-based construction networks (BbCNs). Though BIM is increasingly adopted and implemented across the construction industry, the problems associated with the lack of collaboration among teams in BbCNs remain a major hindrance to reaping the full potential of BIM. Previous studies have been conceptual in nature. This paper, therefore, attempts to modify and validate existing conceptual models that describe collaboration in BbCNs.

Design/methodology/approach – To modify the conceptual model for collaboration in BbCNs, qualitative data through semi-structured interviews with BIM experts in the industry were collected and analysed using qualitative methods including the use of NVivo software.

Findings – The proposed model includes influential factors and their sub-factors to collaboration in BbCNs, as well as considering their indicators. Findings reveal that several overlooked concepts, particularly unfavourable BIM contractual arrangements, act as the root causes of the unwillingness of team members in BbCNs to engage in collaborative efforts.

Research limitations/implications – The study's findings must be viewed in light of several limitations. First, the interviewees in this study were based in Australia hence their perceptions of BIM collaboration are reflective of the sociotechnical setting of BIM-enabled projects in this country. Also, the findings are based on the perception of experts in the field, rather than analysis of performance measures or quantitative assessment of associations among collaboration outcomes and various factors. This, however, provides the field with fertile grounds for future research.

Practical implications – The study benefits researchers by shifting the collaboration discourse in BIM-enabled projects from technology-related issues to the people and contractual-related domains. Moreover, the developed qualitative model provides industry professionals with a point of reference to improve collaboration on BIM-enabled projects.

Social implications – The study benefits researchers by shifting the collaboration discourse in BIM-enabled projects from technology-related issues to the people and contractual-related domains. Moreover, the developed qualitative model provides industry professionals with a point of reference to improve collaboration on BIM-enabled projects.

Originality/value – Arguments provided in this study highlight the necessity of considering the contractual arrangement of BIM-related projects and foster the willingness of team members to collaborate. This can be addressed using clear and comprehensive BIM execution plans and clearly explaining the role of BIM managers in the process.

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# 1. Introduction

Building information modelling (BIM) is the future trend, a relatively new disruptive innovation for the construction industry (Tulubas Gokuc and Arditi, 2017). The pervasiveness of BIM is exponentially on the rise (Liao and Teo, 2018). The global BIM market is projected to grow to $11.7bn by 2022, a compound annual growth rate (CAGR) of 21.6% during the forecast period 2016–2022 (Lanjudkar, 2016). This presents industry with challenges on multiple fronts, not least of which is the necessity to conform to new contractual, behavioural and organisational norms within BIM-related inter-organisational units (Poirier *et al.*, 2017; Elghaish *et al.*, 2019).

The major inter-organisational units utilised on current BIM-enabled projects are BIM-based construction networks (BbCNs), namely teams put together from experts of several specialist organisations to deliver BIM-related tasks (Oraee *et al.*, 2017b). Collaboration among members of BbCNs is recognised as the key to success for BIM-enabled projects (Ashcraft, 2008; Poirier *et al.*, 2017). Nevertheless, this collaboration is still a serious challenge that affects BIM-enabled projects (Mignone *et al.*, 2016; Merschbrock *et al.*, 2018; Elghaish *et al.*, 2019). Evidence obtained from industry acknowledges this challenge. According to the UK BIM Alliance, “it is the need for closer collaboration that's holding us back.” (Kemp, 2017). There remain significant legal barriers, conflicts of interests and business considerations that make practitioners shy away from open collaborative processes on BIM-enabled projects (Liu *et al.*, 2016).

With the above in mind, there have been various attempts to address the issue of collaboration in BbCNs (Oraee *et al.*, 2017b). A review of the literature shows that many scholars have tried developing innovative technologies to facilitate collaboration (Sacks *et al.*, 2018; Elghaish *et al.*, 2019). However, research on collaboration in BbCNs is dominated by the technology discourse (Oraee *et al.*, 2017a), focussing on the software-central view of BIM (Papadonikolaki *et al.*, 2019) and overlooking the crucial role of people management (Liu *et al.*, 2017), despite the observation that people management is the major source of ineffective collaboration in BbCNs (Liao and Teo, 2018; Merschbrock *et al.*, 2018). Scholars such as Mignone *et al.* (2016), Merschbrock *et al.* (2018) and Li *et al.* (2019) emphasise the role of people, exploring collaboration issues in particular projects and discussing the solutions adopted, but their findings lack the ability to be generalized beyond the immediate settings of their studies. Besides, existing studies tend to focus on narrow areas associated with collaboration in BbCNs, missing the bigger picture; using an analogy, they succeed in providing knowledge on individual trees, but fall short of offering a broader picture of the forest. Consequently, despite the value added to the literature by existing studies, there is still little understanding of the nature and variety of the barriers that hinder collaboration in BbCNs (Oraee *et al.*, 2017b).

The work by Oraee *et al.* (2019) is most applicable to the topic, in which a conceptual model of different barriers and influential factors to collaboration in BbCNs is presented. However, Oraee *et al.* (2019) do not go beyond the theoretical realm in presenting the findings of their study which is based on a literature review. Their conceptual model of collaboration in BbCNs hence remains in need of validation and contextualisation via exposure to empirical data. Addressing this knowledge gap in the literature is the raison d'être for the present study, which extends the work conducted by Oraee *et al.* (2019), by offering empirical validation of the list of factors and barriers provided by exposure to the scrutiny of experts in the field.

# 2. Background

## 2.1 Collaboration in the construction sector

From a behavioural science perspective, Wood and Gray (1991, p. 146) discuss that: *"collaboration occurs when a group of autonomous stakeholders of a problem domain engages in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain."* In the construction context, collaboration describes all situations where various parties work together, for example partnering, alliancing, joint ventures or networking (Hughes *et al.*, 2012). Collaboration in construction therefore largely falls within the procurement discourse (Durdyev *et al.*, 2019; Elghaish *et al.*, 2019). That is, collaboration occurs by adopting delivery methods that establish collaborative arrangements in delivering projects (Kuiper and Holzer, 2013; Hughes *et al.*, 2015). One effective solution – for enhancing collaboration in project delivery – is through adopting technologies that provide project team members with a single shared interface and Common Data Environment (CDE) (Merschbrock and Munkvold, 2015; Charef *et al.*, 2019). The solution relies on using data exchange frameworks and technological innovations that facilitate collaboration (Alreshidi *et al.*, 2017). In response, BIM has emerged as an advanced methodology that provides the needed CDE and facilitates sharing of information and data among various disciplines (Kuiper and Holzer, 2013; Liao and Teo, 2018; Piroozfar *et al.*, 2019), as discussed next.

## 2.2 Building information modelling

The concept of building information modelling (BIM), as identified by the AECO sector in recent years, refers to a set of interacting processes and technologies that are used to integrate and manage essential construction project information in digital format throughout the project life cycle (Succar, 2009; Holzer, 2016). In this context, BIM refers to a technological innovation that provides inter-organisational models and integrates various project stakeholders (Bryde *et al.*, 2013; Garg, 2017); it provides one single point of reference for designers, engineers, contractors, facility managers and owners (Bryde *et al.*, 2013; Sacks *et al.*, 2018). BIM-enabled projects thus require construction professionals to collaborate frequently through a common information-sharing platform (Sackey *et al.*, 2015; Oraee *et al.*, 2019). As their main inter-organisational unit, BIM-enabled projects rely on BbCNs (Oraee *et al.*, 2017b). These comprise groups of specialist organisations contracted to execute BIM-related works (Grilo *et al.*, 2013). In BbCNs, collaborative working is of crucial importance (Mignone *et al.*, 2016). Indeed, enhancing collaboration in project delivery has been a major selling point of BIM (Liu *et al.*, 2017). Collaboration defines the effectiveness and performance in delivering projects (Eastman, 2011; Sacks and Pikas, 2013) and the success of BIM-enabled projects relies on effective collaboration among stakeholders (Bassanino *et al.*, 2014). However, the envisaged potential of BIM remains untapped in the absence of effective collaboration (Zhang *et al.*, 2017; Merschbrock *et al.*, 2018).

## 2.3 Collaboration in BbCNs

With the rise of BIM as the state-of-the-art technology to foster collaboration, BbCNs have become the centrepiece of collaboration on construction projects (Grilo *et al.*, 2013; Liu *et al.*, 2016; Mignone *et al.*, 2016). However, despite the rise of collaboration tools and technologies, collaboration in BbCNs is identified as an underperforming area. According to the study by (Mignone *et al.*, 2016), poor collaboration in BbCNs has resulted in the ineffectiveness and lack of performance in project teams, eventually leading to design clashes, omissions and errors (Sackey *et al.*, 2015). The existing literature shows that collaboration in BbCNs is problematic and requires significant attention for collaboration to be fostered in BIM-enabled organisations and construction projects. In response to the low-performance collaboration capability of BIM, the research by McGraw-Hill Construction (2017) identified that “investment in developing collaborative processes with other parties” is in the top five forecast investments in BIM, as proposed by major stakeholders (architects, engineers and contractors) in the AECO sector. Moreover, the report focused on very high-level BIM-engaged global contractors with the findings illustrating that “improving collaboration (both internally and externally) between project major stakeholders” is in the top five future BIM investment strategies for these contractors. Ashcraft (2008) proffered the view that a BIM-enabled project in the absence of collaboration is akin to merely “scratching the surface” in terms of realising the software's full capability. This highlighted the crucial role of access by major stakeholders to interoperable processes, software and packages for BbCNs (Grilo and Jardim-Goncalves, 2010; Hu *et al.*, 2016).

## 2.4 Enhancing collaboration in BbCNs

As discussed, collaboration stands at the centre of BbCNs (Grilo *et al.*, 2013; Mignone *et al.*, 2016). Despite this, collaboration in BbCNs is a challenge (Sacks *et al.*, 2018; Oraee *et al.*, 2019); it remains an unresolved problem and the topic, therefore, forms one of the core clusters of BIM-related research (Durdyev *et al.*, 2019; Lemaire *et al.*, 2019; Oraee *et al.*, 2019).

Previous studies on the topic have recommended various approaches to enhancing collaboration in BbCNs. These include, for the major part, enhancing the functionality of technology and developing new technologies that facilitate collaborative working (Wang *et al.*, 2014; Sacks *et al.*, 2018; Elghaish *et al.*, 2019). Moreover, developing data exchange protocols and working arrangements that support collaboration are other avenues explored (Kassem *et al.*, 2014; Merschbrock and Munkvold, 2014; Elghaish *et al.*, 2019). Indeed, focussing on technology to enhance collaboration has dominated research on the topic (Cao *et al.*, 2016; Oraee *et al.*, 2017a; Merschbrock *et al.*, 2018), but research focus has overlooked the significant impacts of the people management components that influence collaboration in BbCNs, a point argued by Liu *et al.* (2017), Merschbrock *et al.* (2018) and Liao and Teo (2018), among others.

Scholars have thus covered a wide range of sociotechnical factors in addressing the issues of ineffective collaboration in BbCNs, focussing on the technology-oriented perspective, as well as human-computer interactions and people management (Jin *et al.*, 2017; Matarneh *et al.*, 2019). Nevertheless, as discussed, the extant literature on the topic suffers from various shortcomings, the result of which is that detailed knowledge of the nature and variety of the pool of factors and barriers that affect collaboration in BbCNs is yet to be acquired. This is discussed next.

## 2.5 Summary and gap

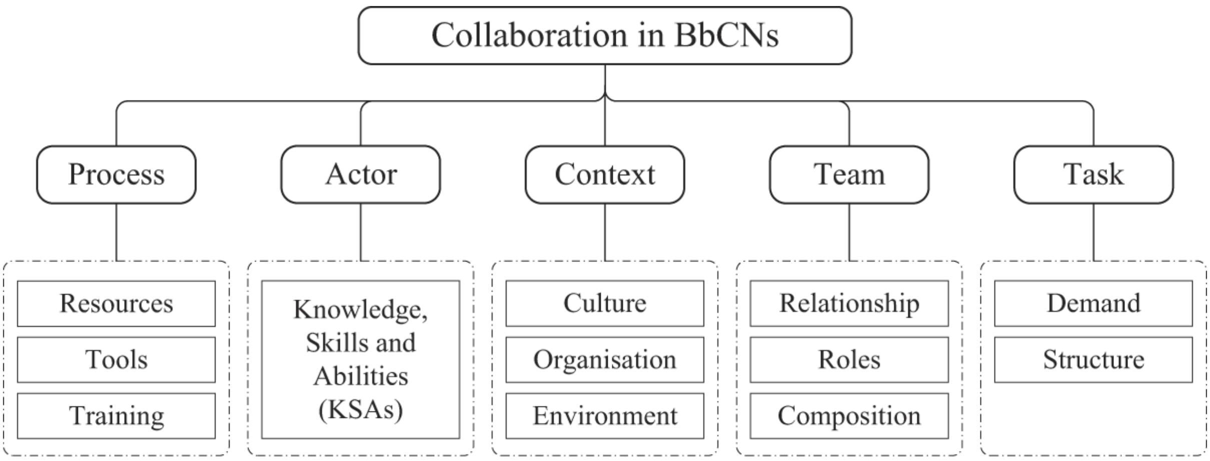
The failure of industry practitioners in shifting common practices to foster collaboration among members in BbCNs remains and omnipresent and vexing problem (Poirier *et al.*, 2016; Oraee *et al.*, 2017a; Alreshidi *et al.*, 2018). Identifying the barriers that act as the root causes behind this problem is a predicate to provide remedial solutions (Merschbrock *et al.*, 2018). And studies to address this need remain much needed in the related literature. To the best of the authors' knowledge, the only scholarly work available in the field is a conceptual model of barriers to collaboration in BbCNs developed by Oraee *et al.* (2019). Indeed, this conceptual model lacks validity and recognition from field experts, as the authors argue (cf. Oraee *et al.*, 2019). This gap is the driving force behind conducting the present study, that is, the motivation is to modify and validate this published conceptual model through collecting empirical data via interviews with BIM professionals in the industry. The conceptual model is described as follows.

## 2.6 The conceptual model

According to Oraee *et al.* (2019), factors that hinder collaboration in BbCNs are grouped within major constructs (process, actor, context, team and task) and their sub-factors (as illustrated in Figure 1).

**Figure 1**

Conceptual model for collaboration in BbCNs




**Source(s):** Adapted from Oraee *et al.* (2019)

The construct "Process" refers mainly to the technical side of collaboration which includes resources and tools, as well as relevant training for collaboration. "Actor" refers to the knowledge, skills and abilities (KSAs) in BIM that are required by people working in the process of collaboration in BIM-enabled organisations and projects. "Context" reflects the specific environment that all these identified factors are set within, whilst "Team" reflects the roles and relationships between a group of actors from different disciplines and/or organisations working collaboratively to deliver BIM deliverables and eventually the project. Finally, "Task" refers to the nature of BIM tasks including demand and their structure.

# 3. Research methods

## 3.1 Research approach

Collaboration in BbCNs is still a less explored area. As proposed by Neuman (2006) and Punch (2005), investigating a "little-understood phenomenon" requires the deployment of qualitative techniques for collecting data from the field. To be specific, as argued by Ahmed *et al.* (2016), qualitative studies are best suited to careful explorations of the real-life practices and experiences of the actors involved in the topic of the study (Oraee *et al.*, 2017b; Merschbrock *et al.*, 2018). Given the emphasis of this study on validation through experts, a qualitative approach was deemed suitable. Conducting interviews is one of the most effective methods for undertaking a qualitative approach. As mentioned, this study aimed at presenting the conceptual model to subject matter experts and build confidence in the applicability and confidence in the model through conducting interviews with these experts. The aim was engaging in conversation with experts about the model, to modify, confirm and add/remove components. As argued by Andersen *et al.* (2012), this is a common approach by researchers, which can be used for verifying accurate models that present the nature of relationships and show interactions among various components like system dynamic models. In fact, using interviews to modify conceptual models is an acceptable practice in the literature (Black, 2002). Moreover, interviews can assist researchers to use existing theories in facilitating the emergence of granular knowledge and validating existing knowledge using data from the context at hand (Creswell, 2014).

According to Creswell (2014, p. 65) *"… the theory may appear at the beginning and be modified or adjusted based on participant views"*. This is the purpose of considering interviews as the qualitative method to be utilised in this study. Indeed, findings from interviews will assist the researcher to refine the framework on collaboration in BbCNs. As inferred by Rowley (2012, p. 262), *"the most common type of interview is the semi-structured interview"*. Deploying semi-structured interviews in the present study was aimed at providing a basis for modifying the theoretical framework of the study on collaboration in BbCNs.

## 3.2 Sampling

Interviewees were selected using the "purposive sampling," namely, *"… sampling in a deliberate way, with some purposes or focus in mind"* (Punch, 2005, p. 187). Purposive sampling enables researchers to fulfil the research objectives and simultaneously use and control the level of variation among interviewees. Interviewees were therefore recruited by taking into consideration a trade-off between the following criteria (cf. Bazeley, 2013), viz:

1. Sample heterogeneity: Adequate variation among interviewees to allow for comparative analysis and
2. Sample homogeneity: Limited variation to allow for intensive study.

The trade-off was considered to balance the level of homogeneity among participants and ensure access to a sample of participants whose attributes are adequately heterogenous, as recommended by Robinson (2014). By maintaining a measure of sample homogeneity, data acquired from all participants will be deemed reliable and applicated within a defined setting, where all participants satisfy one common criterion: the possession of an adequate experience and knowledge on the key concepts related to study's topic. The rationale of selecting a reasonably heterogeneous sample is that any commonality found across participants is more likely to be a widely generalisable phenomenon than a commonality found in a homogenous group. Therefore, heterogeneity of a sample helps provide evidence that the findings generated are not solely reflective of one category of participants like designers. Having participants belonging to different groups and professional categories will assist in arguing that findings apply to various groups within the current research setting (Robinson, 2014).

The number of interviewees was considered to be between three and 16, as a reasonable preliminary estimation for defining the sample size (Bazeley, 2013). Thus, an initial list of 54 BIM experts (potential interviewees) was identified, who had relevant expertise in BIM and considerable years of experience working in the Australian construction industry. It is noteworthy to mention that the number of BIM experts is constrained to a limited pool of practitioners. The list was prepared by targeting individual members of groups dedicated to BIM in social professional networks such as LinkedIn, recommended as a reliable source for assessing experts' qualifications (Julie *et al.*, 2014). The concept of saturation must be considered for qualitative studies that use *purposive sampling*. Bazeley (2013) states that saturation is the point at which *"no new information is being added to coding categories (data saturation) or to the emerging theories (theoretical saturation) through adding further cases to the analysis."* The present study's protocol for recognising the point of saturation was the point at which after three interviews, no new code or theory emerges (Hosseini *et al.*, 2016). As a result, interviews were stopped after conducting interviews with 11 interviewees (i.e. saturation point was reached after the 8th interview), whose profiles are detailed in Table 1. In terms of the adequacy of the number of interviewees, as discussed, generally there is a limited pool of experts in this field with reasonable experience in BIM and collaboration. Indeed, many self-claimed BIM experts (e.g. BIM drafters) only have knowledge and skills in developing models and may not be involved in the collaboration process. So, this further limits the pool of experts for data collection. In this research and during the interviews, most of the findings were found through the first eight interviews. After these eight interviews and through the next three interviews, no new code was found, showing saturation in the collected data. As discussed by Bazeley (2013, p. 50), saturation can be reached with any number of interviewees and this could be between six and 12. As a result, given the limited pool of BIM experts, having 11 respondents in the present study provided a reasonable and acceptable sample size for collecting qualitative data.

Table 1 illustrates that interviewees had a minimum of three years and a maximum of nine years of experience in working with BIM. The type of organisations they are working in are ranged from architectural and engineering (A/E) to general contractor (GC), and construction infrastructure and real estate (CIR) firms. The location was also incorporated in interviewee selection – in this case, Australia. For a number of interviewees, team members were dispersed across a city or a state in Australia, while for others, team members were scattered across the globe. Moreover, the size of each interviewee's employer organisation was also included in the selection criteria. As a result, the categorisation for construction organisations was thematically clustered into two dichotomous groupings of either small-medium or large-sized organisations. Thus, the sampling strategy in the current study was “maximum variation”, which is a subset of purposive sampling. As argued by Kitto *et al.* (2008, p. 244) *“… maximum variation is the ideal when a holistic overview of the phenomenon is sought”* – this is certainly the case for the present study.

# Table 1

Interviewees' profiles

| No | ID | Occupation | Experience in Total (Year) | Experience in BIM (Year) | Organisation type | Project size | Team's geographical spread |
|---|---|---|---|---|---|---|---|
| 1 | A | BIM MEP manager | 16 | 3 | Building services | Large | Globally |
| 2 | B | BIM MEP designer | 15 | 5 | A/E | Large | Australia |
| 3 | C | BIM consultant | 12 | 3 | Design | Small-medium | Australia |
| 4 | D | BIM manager | 17 | 5 | Building services | Large | Australia |
| 5 | E | BIM leader | 17 | 8 | GC | Large | Australia |
| 6 | F | BIM advocate | 18 | 9 | A/E | Large | Globally |
| 7 | G | BIM manager | 11 | 8 | Fire consultancy | Small-medium | Australia |
| 8 | H | BIM consultant | 20 | 3 | Architectural | Small-medium | Australia |
| 9 | I | BIM manager | 14 | 7 | CIR | Large | Globally |
| 10 | J | BIM consultant | 27 | 4 | GC | Large | Melbourne |
| 11 | K | BIM consultant | 16 | 8 | A/E | Large | Globally |

**Note(s)**: A/E: Architectural and Engineering

GC: General Contractor

CIR: Construction, Infrastructure and Real estate

### 3.3 Data collection

Of the 11 interviewees, two agreed to attend face-to-face interviews, whilst nine interviews were completed over the phone. An integral part of the interview procedure adopted was for the interviewer to first explain to the interviewee the concept of collaboration in BIM-enabled construction projects and further elucidate upon the study's objectives. Then, once the researcher had ensured that the interviewee's interpretation of collaboration in BIM projects was consistent with the definition of collaboration in the present study, the main questions were posed and discussed. Each interview lasted around 45–60 min with the interview being audio recorded.

The interview sessions were mainly focused on modifying the conceptual model developed by Oraee *et al.* (2019), as illustrated in Figure 1, thus ensuring that it met the study objectives of being a practical model and applicable to the construction industry. During the interview sessions, interviewees were asked to discuss the challenges (barriers) in collaboration in BbCNs and add any factors and/or sub-factors that were not included in the conceptual model. This common application of qualitative research ensures that the research findings remain connected to the existing body of knowledge whilst simultaneously creating new knowledge (Bazeley, 2013).

## 4. From interviews to model development

In this study, NVivo (developed by QSR International Pty Ltd.) was utilised as a qualitative data analysis software tool, given its capabilities for providing in-depth insight into collected data and the benefits, it provides for indexing, marking and sorting qualitative data with greater speed, accuracy and flexibility (cf. Bazeley, 2013).

### 4.1 Data analysis

Coding is the process of assigning names, tags or labels to different pieces of unstructured data – in this case, transcripts from interviews (Punch, 2005). This study utilised a mixed approach that involved the integration of deductive and inductive coding: codes were developed in view of the existing literature (theory-driven codes) in tandem with interviewees' subjective views (data-driven codes). A well-established method for assigning either theory-driven or data-driven codes is to focus upon similarity, comparison and contrast against a theoretical structure (Bazeley, 2013). Thus, the theoretical structure – namely the conceptual model, illustrated in Figure 1 – was used to organise the emerging themes and codes. The conceptual model set the foundation for empirical fieldwork, during which collected qualitative data were interpreted and then coded against the relevant factors that

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hinder collaboration in BbCNs. Through this coding and analysis, factors in the conceptual model were either confirmed, modified or removed. Any new factors and sub-factors identified were created in addition to the confirmed or modified factors in the conceptual model. Figure 2 illustrates the process of comparing the conceptual model to the findings of the qualitative analysis in the present study.

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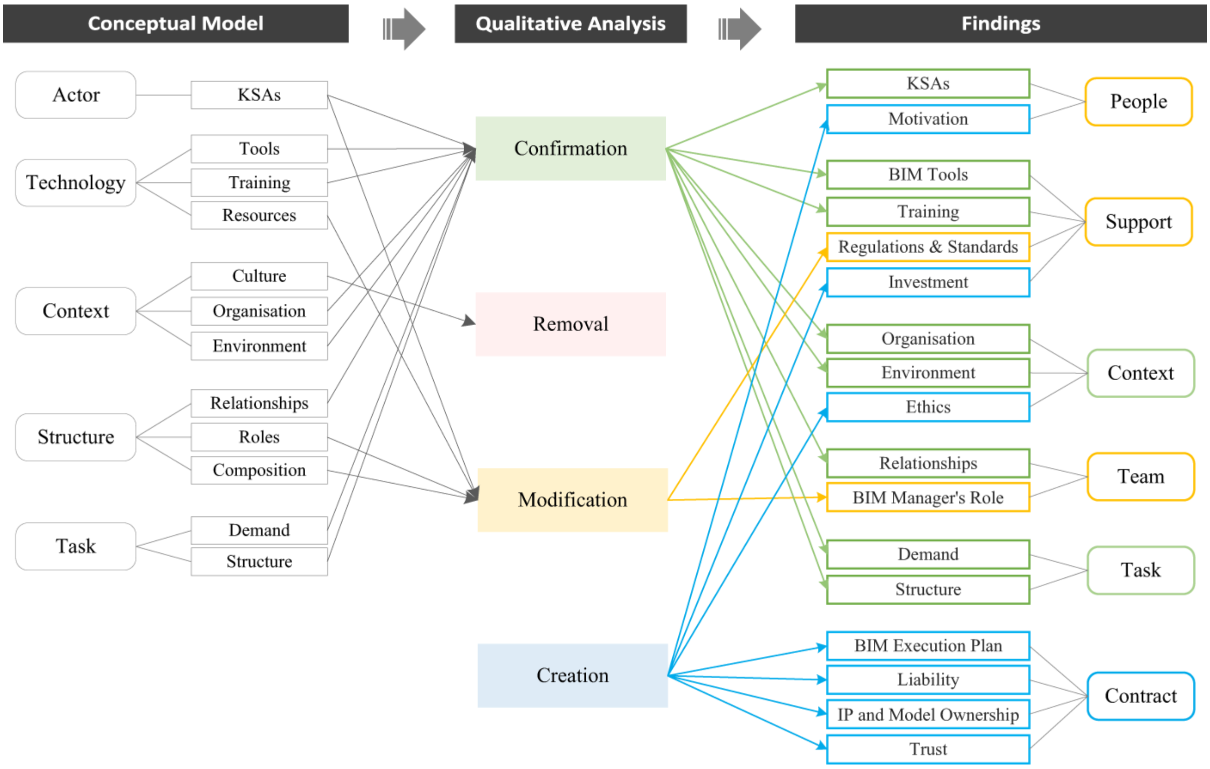
## Figure 2

Model development: from conceptual model to findings in qualitative analysis



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The coding process resulted in the generation of 28 different codes (barriers) under which 511 passages of text were coded. The coded passages were then thoroughly investigated with multiple themes being merged and categorised under main codes. Eventually, 17 themes (sub-factors) were identified as the ones influencing collaboration in BbCNs and these were categorised under six main constructs (see Figure 2). Of the six identified constructs, three (*context, team* and *task)* had been previously been identified and demonstrated in the form of the study's theoretical background (see Figure 1). The terms referring to *actor* and *process* were changed to *people* and *support* respectively, as recommended by interviewees, and a new term called *contract* was identified. To reiterate, the six constructs identified were

1. People: reflecting BIM knowledge, skills and abilities and motivation of the people in the AEC industry.
2. Support: representing relevant BIM standards and regulations, investments, BIM tools and training.
3. Context: referring to environment, ethics and organisation.
4. Team: representing relationships and BIM manager role in teams.
5. Task: capturing the demand and structure of BIM tasks and
6. Contract: an inclusive term to encompass engagements and agreements among BbCN members, reflecting BIM execution plan, liability, trust, intellectual property (IP) and ownership aspects.

In qualitative analysis, the number of references to a code could be regarded as the relative importance of the item, as perceived by interviewees, the reason being: more important items are repeated more frequently across interview transcripts. The use of the frequency of coded words as a measure for identifying the most important or key ideas is an acceptable practice in the literature (Bazeley, 2013). To this end, in the present study, relevant passages/sentences in the interviews' transcripts were allocated to the relevant codes (factors to BIM collaboration), resulted in the creation of Figure 3 by showing the number of words discussed around each code during the interviews. In other words, Figure 3 illustrates the relative importance of items within the coding tree in view of the number of words used by the interviewees to discuss the codes, where the rounded rectangles represent the constructs and the squared rectangles represent the factors.

As illustrated in Figure 3, *people* is considered to be the most important constructs followed by: *support*, *contract*, *context*, *team* and *task,* respectively; a description of each follows.

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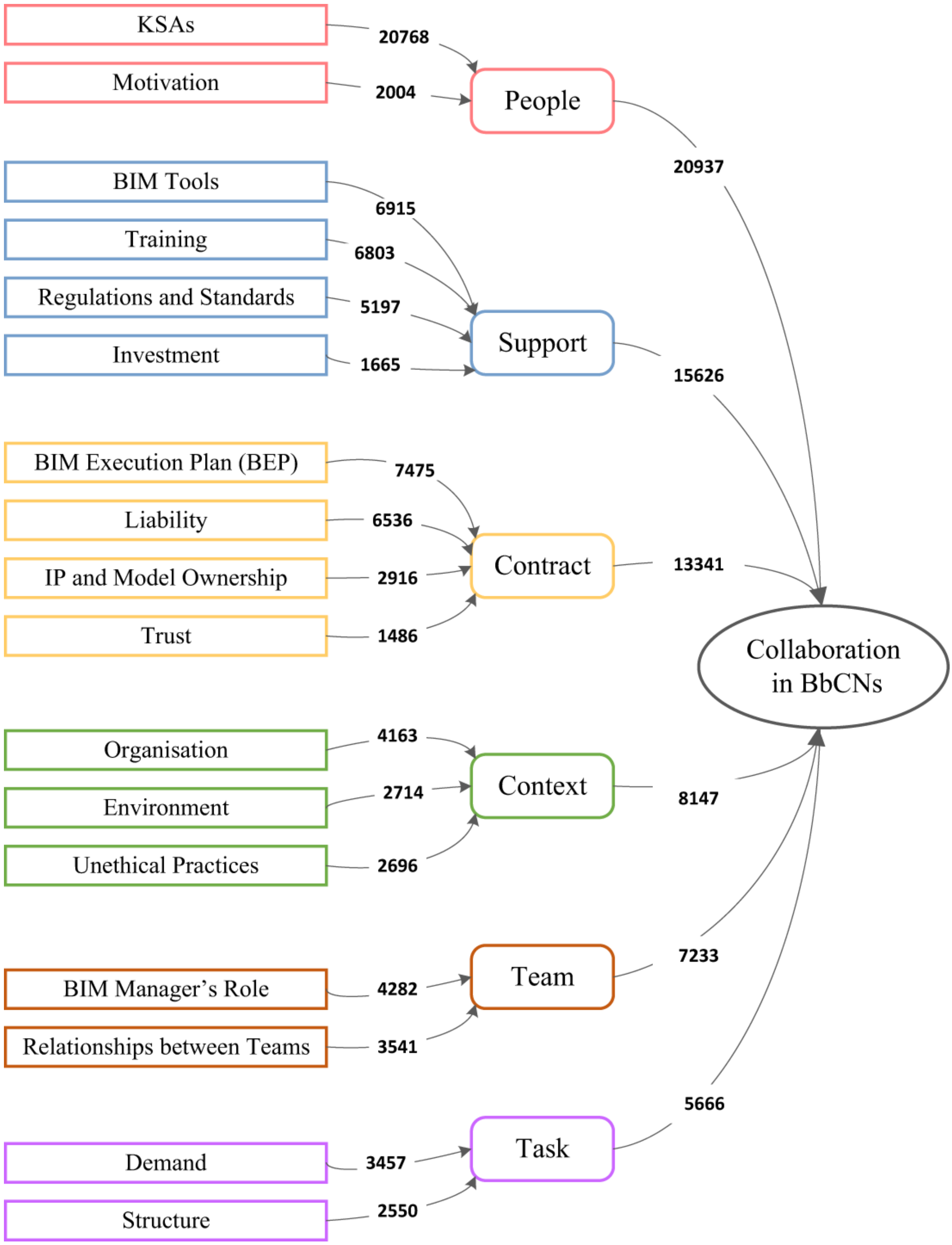
**Figure 3**

The relative importance of identified factors and constructs based on the number of words coded (number on the arrows)



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## 4.2 People

Based on the interviewees' perceptions, the *people* factor was found to be the most critical construct affecting collaboration in BbCNs, with a total of 20,937 words used across the interview transcripts to discuss its impact (see Figure 3). All the interviewees emphasised the lack of “*knowledge, skills and abilities (KSAs)”* of people working within the industry and six also mentioned the impact of “*motivation*”. Hence, the KSAs of practitioners were found to be the most serious barriers to collaboration in BbCNs (Table 2).

# Table 2

People-related factors and barriers

| Sub-factor | Barriers |
|---|---|
| Knowledge, skills and abilities (KSAs) | Insufficient understanding of the BIM process by the people working in the industry |
| | Lack of clients' knowledge on BIM deliverables |
| | Lack of understanding of the collaboration process in BIM |
| Motivation | Lack of motivation from people to get trained in BIM |

### 4.2.1 Knowledge, skills and abilities

According to interviewees, insufficient knowledge of the BIM concept and its applications still presents influential barriers to collaboration. That is, many in the industry still believe that BIM is all about developing a 3D model using software like Autodesk Revit, during the design stage:

… there are people who do not have sufficient BIM knowledge but still work on BIM projects. The reason is that some of their organisations do not understand the concept of BIM properly or they do not have the in-house skillset or knowledge (Interviewee B).

Similarly, a lack of clients' knowledge and resources regarding BIM deliverables was identified as another important barrier. Almost all interviewees agreed that many clients generally do not understand BIM deliverables and what they eventually will receive as the outcome of implementing BIM. This usually results in signing contracts with unclear BIM requirements and deliverables, unproductive communications and potential disputes between clients and other parties in the contract. In addition, interviewees stated that there was a lack of understanding and knowledge by project members of the BIM collaboration concept itself. This concept is simply overlooked by many in the industry due to lack of awareness of the fundamental dimensions of BIM.

### 4.2.2 Motivation

The lack of motivation of project members to be trained and acquire secure knowledge in BIM was identified as a barrier. This was highlighted by the interviewees during the discussion on the role of BIM training and education in increasing BIM and collaboration KSAs of the people in the industry. Interviewees acknowledged that whilst tuition-free training courses and workshops on BIM and collaboration are provided by employers and software vendors, the attendance rate at those workshops is very low. In other words, while many team members have limited (if any) knowledge of the process of BIM collaboration, still they are not interested in attending training sessions:

… it's still a big problem for project members to commit to some time to be trained and then to actually follow the processes trained on. My sole job was to pull people by the sleeve and say let's meet, let's do this workshop, let's do the training and stuff like that, and if you've never tried doing this you'll be surprised how many people refuse to do it (Interviewee C).

## 4.3 Support (infrastructure)

The *support* construct is the second most important affecting collaboration in BbCNs, with 15,626 words referring to it (refer to Figure 3). Specifically, *support* was seen to significantly influence collaboration by providing relevant resources and facilities, including technological support, training, initiating relevant standards and regulations and investments in relevant BIM support tools. Analysis of the findings therefore demonstrates that *support* incorporates four sub-factors viz: “BIM tools”, “training”, “regulations and standards”, and “investment” (see Table 3).

# Table 3

Support-related factors and barriers

| **Sub-factor** | **Barriers** |
|---|---|
| BIM tools | Interoperability challenges in BIM tools across the project life cycle |
| | Complexities of adopting BIM and collaboration tools |
| | Collaboration tools fail in delivering their promises |
| | Lack of use of Common Data Environment by SMEs |
| Training | Insufficient BIM education within the universities and institutions |
| Regulations and standards | Lack of transparent standards around BIM models and collaboration |
| Investment | Lack of investment in BIM and collaboration tools |

### 4.3.1 BIM tools

Tools and software play significant “technical support” roles in the BIM process and collaboration. According to the interviewees, BIM tools have been adequately developed over the past few years and can provide sufficient functionality for the BIM process and collaboration. It is noteworthy to mention that, while a lack of “common data environment (CDE)” was previously identified in the conceptual model of this study, all those interviewed acknowledged that lack of CDE is no longer a barrier:

…common data environment is absolutely there, it's been there for quite a while and it's been used by most of the projects of any decent size. I mean, I've seen on news there's a famous toilet building project in Melbourne that used Aconex, so a rather small project (Interviewee C).

Despite the removal of CDE from the list of barriers, interviewees believed that the shortcomings of BIM tools still affect collaboration in BbCNs, with the main issue being the interoperability challenges across the project life cycle, particularly between various tools. Although there are a few interoperable formats such as IFC or BCF available, these formats are not widely accepted by all BIM tools and require standards to be updated and vendors to improve their software accordingly. A further issue identified was the complexities involved in the adoption of BIM and collaboration tools. Almost all the interviewees (9 out of 11) acknowledged that the increasing number of available BIM tools in the industry inadvertently complicates an organisation's decision-making ability to select the right tool.

Interviewees went on to argue that there are too many BIM tools available in the industry, each one claiming to be comprehensive enough to meet an organisation's needs. However, many of these tools are complicated to learn and work with. Besides, discussions indicated that many existing collaboration tools do not perform as claimed by the vendors, resulting in the wasting of time and money for organisations and significantly affecting collaboration:

The other big issue with the BIM tools is (1) the software is very expensive but (2) when you pull it out of the box it's empty. It's like been given the shell of a car (Interviewee F).

Interviewees were also in agreement that the lack of use of a CDE by small to medium enterprises (SMEs) is another barrier. As discussed, they believe that although CDE is widely available within the BIM environment, many SMEs involved in BIM-enabled projects still resist adopting CDE within their firms; they prefer to collaborate and complete their tasks traditionally. This has a significant impact on collaboration in BbCNs.

### 4.3.2 Training

According to the interviewees, there is an insufficient amount of BIM education within universities and training institutions, which was classified as a barrier to collaboration in BbCNs under the *training* construct. In fact, all interviewees agreed that there is a lack of integrated BIM training within both industry and higher education institutes (HEIs). The lack of integrated training in BIM within the industry gives rise to a disparity in people's knowledge of BIM. Organisations find the existing training courses unproductive and a waste of invaluable time and money, thus they run internal workshops and training sessions on BIM, in particular for older generations of staff, who are more resistant to change. Moreover, due to the lack of integrated BIM education within HEIs, graduates have a different level of understanding of BIM, tools and collaboration in BIM. The interviews emphasised the need for organisations to train new graduates that are fit to work within BIM-enabled construction projects:

… the other big issue is the training. There's BIM education just on the software platforms, but no education on the actual BIM process. If you've got BIM knowledge as well as building knowledge, then you're able to design and document BIM projects efficiently (Interviewee F).

### 4.3.3 Regulations and standards

Analysis of interview findings indicates that the standards relating to BIM models and BIM collaboration are insufficiently transparent and this underlines the necessity of access to such. According to the interviewees, there are some standards and regulations on BIM models, but as they are not transparent enough, each organisation forms its own interpretation. The levels of development (LOD) in BIM models were referred to as an example, for which each party has its own understanding of a specific level, resulting in team members failing to agree on an acceptable LOD for their shared models. The collaboration process in BbCNs also requires transparent standards and regulations, so that all parties in the project can collaborate effectively:

… for example, saying something like LOD 200 means what we call approximate size and location which is left up to interpretation and you cannot really coordinate off that. So, whatever you put in the model there's a loophole for engineers and subcontractors to say well this is what our interpretation was (Interviewee I).

### 4.3.4 Investment

The lack of investment in BIM and collaboration tools is also viewed as a barrier by the interviewees. The analysis revealed that many organisations, especially smaller companies, are still fearful of shifting to BIM. Though they are involved in BIM-enabled projects, they maintain a traditional *modus operandi.* When they are not sure about the tasks, they prefer to outsource the task to another organisation. This approach results in an unproductive collaboration between them and other BIM-enabled organisations. The main reason behind this approach was found to be the lack of willingness to invest in BIM tools and platforms and concerns regarding the return on investments (ROI). An investment in BIM tools (sometimes to create a “BIM-wash”) will result in an extension of fees which may result in jobs being lost:

For example, with Revit and Navisworks, it's about $14,000 to buy software and then about $1000 maintenance per year plus training etc., which is very expensive as a startup cost, especially for smaller builders (Interviewee I).

## 4.4 Contract

The *contract* construct was found to be influential on collaboration in BbCNs; this is a new phenomenon that emerged out of the interviews. Analysis of interview transcripts demonstrated that the *contract* construct is actually one of the major areas that affect collaboration in BbCNs, being the third most significant with 13,341 words referring to it (see Figure 3). A novel insight into the impacts of *Contract* in BIM-enabled projects on collaboration emerged, with four main factors identified: “BIM execution plan (BEP)”, “liability”, “intellectual property (IP) and model ownership” and “trust” (see Table 4 for details).

# Table 4

Contract-related factors and barriers

| Sub-factor | Barriers |
|---|---|
| BIM execution plan (BEP) | Lack of transparent BIM execution plan and its framework |
| | People in charge of the BEP being engaged at the wrong time |
| Liability | Lack of transparent contract among different disciplines |
| | Data liability – the responsibility of actors on their own work |
| Intellectual property and model ownership | Concerns around model ownership and sharing intellectual property |
| Trust | Lack of trust (contracting and collaborating with whom they trust) |

### 4.4.1 BIM execution plan

In BIM-enabled projects, the BEP is treated as the core agreement which delineates how the BIM project is to be delivered. The purpose of the BEP is to allow project teams to agree on the way models and associated information is shared, how these models are put together and who is responsible for advancing certain components inherent in a multidisciplinary BIM process. Interviewees believe that the lack of a transparent BEP and accompanying framework is a serious barrier to collaboration:

…it is still not entirely well-defined at the beginning of the project, who is going to be doing what or who is going to be in charge of BIM coordination in particular. And that can sometimes be a cause for confusion or sometimes the biggest challenge is transferring from design into construction, and who takes care of the BIM coordination when the project starts (Interviewee D).

Another barrier to collaboration in BbCNs that was identified was that the people in charge of the BEP are engaged at the wrong time. Almost all interviewees believed that the BEP should be developed at the beginning of a BIM project and involving all relevant teams and people. However, while the BEP is usually developed at the project start, it fails to include all responsible teams and stakeholders. Teams do eventually engage in the process, but this delayed involvement results in clashes, inefficient collaboration and reworks, and eventually slows down the design and construction process.

### 4.4.2 Liability

Data liability was recognised as a factor influencing collaboration in BbCNs. According to the interviewees, while BIM models are shared among different disciplines and organisations, each discipline must be responsible for their modifications and inputs to the model. This becomes a serious challenge, for example, where architects sign agreements with clients to accept responsibility for the final BIM models and deliverables. To develop the BIM model, architects need to collaborate with other disciplines such as structural engineers, MEP engineers, contractors and supply chains (SC), thus transparent agreements between different disciplines are essential to improve coordination and ensure data liability is shared amongst every single discipline who inputs into, or changes, the model:

… for example, I've sent a structural engineer a BIM model, they moved a beam. They send it back to me that updated model. Now, who's responsible for the location of that beam? The architect. So, even though the engineer has changed the location, it's ultimately the architect's responsibility for the location of things. So, that is what I try to fix because there is no contract between the architects and consultants (Interviewee H).

### 4.4.3 Intellectual property and ownership

Also within the *contract* construct, the concerns relating to sharing intellectual property (IP) and BIM model ownership were found to be barriers to collaboration in BbCNs. According to interviewees' perceptions, teams in BIM-enabled projects are reluctant to share their full models with other disciplines, due to concerns around their IP, i.e. that these intellectual contributions could be used by their competitors, especially within the supply chain discipline. It was found to be similar to BIM model ownership, where any party that had contributed to the model claimed the right of ownership. For example, upon receiving and updating a BIM model from another discipline, ownership of the model becomes a challenge for the involved teams, where any party that has partially modified the model claims ownership.

BIM collaboration, but not to the client! Now we have a policy here of not sending ArchiCAD files to clients. Because we had one client, he wanted us to give him the BIM model. So, I gave him the model, then I noticed he gave it to another architect, re-documented the house in AutoCAD, stacked it all up using his own joinery (Interviewee K).

### 4.4.4 Trust

Interviewees stated that on many occasions collaboration occurs through verbal communications hence “trust” plays a major role in day-to-day collaboration. Collaboration in BbCNs does not occur unless trust is established. This was justified by the interviews, referring to the fact that construction projects are bespoke and may not be repeated in the future, with the same people. This lack of history and continuity means that individuals remain reluctant to collaborate:

In the BIM world and in the design and construction stages, in particular, most collaboration occurs through verbal agreement and maybe an email to consolidate it, but a lot of trust is involved and a lot of on the spot commitment to which action is relied upon (Interviewee G).

### 4.5 Context

The *context* factor was acknowledged by the interviewees as the fourth most important construct, with 8,147 words referring to it (see Figure 3). The "Context" was seen to significantly influence collaboration in BbCNs through organisations' context and the environment in which project teams work. Moreover, the attitude of organisations towards collaboration in BbCNs was considered influential. As illustrated in Table 5, interviewees argued that "Context" has three dimensions: "organisation", "environment" and "ethics".

# Table 5

Context-related factors and barriers

| Sub-factor | Barriers |
|---|---|
| Organisation | Disparities in collaborative approaches among organisations |
| Environment | Dynamics and fragmented nature of the industry |
| Ethics | Lack of willingness or interest to enforce the guidelines and standards |
| | Promoting or dictating specific collaboration tools |

It is noteworthy to mention that the sub-factor "culture" (national culture identified in the conceptual model) was not found to be an influential factor for collaboration in BbCNs; as a result, "culture" was removed from the list of barriers. Interviewees all believed that the Australian construction industry is multicultural by nature hence national culture and the language barrier cannot be seen as barriers to collaboration:

Our office is multicultural. We've got two Columbians, one Iranian, Indonesian, Singaporean, a couple of Australians like Caucasian Australians, one Russian and one from Chile who formed our Melbourne office. So, the platform is an international brand and works very well (Interviewee H).

#### 4.5.1 Organisation

Interviewees discussed this barrier in terms of organisational work culture and structure and approaches to collaboration. They agreed that disparities in collaboration approaches among organisations are influential, as different companies have different structures and ways to collaborate with each other. Besides, each company has its own work culture in terms of collaboration and communicating with other organisations.

… every organisation has their own agenda and having their own financial targets to meet and that obviously affects collaboration because every member of the team views themselves as person foremost part of their own organisation protecting their own organisations and then only after that as parts of a project team (Interviewee D).

### 4.5.2 Environment

The environmental factor was identified as another significant barrier to collaboration in BbCNs. Interviewees believed that the AEC industry's inherently dynamic and fragmented nature has a significant impact on collaboration activities within and among collaborating organisations, including supply chains. Furthermore, organisations involved in BIM-enabled projects are frequently located in different geographical locations, cities, states or countries. This necessitates having more online collaboration and meetings, which further exacerbates the challenges.

### 4.5.3 Ethics

According to the interviewees, the unethical practices of people and organisations involved in BIM-enabled projects have adverse impacts on collaboration. A lack of willingness or interest to enforce the existing guidelines and standards was identified as an important barrier. Many interviewees believed that while useful guidelines and standards on BIM exist, many organisations and people still ignore these and prefer to follow their own traditional approach to communicate and deliver projects.

Moreover, a few interviewees believed that some contractors prefer to not fully implement BIM and its guidelines within their organisations. Hence, although they are aware of the benefits of BIM and its cost-efficient process, they “unethically” and opportunistically shy away from collaborating in implementing guidelines because they believe that they will have more change requests and hence, opportunities to make more money out of these:

… when you go to head contractors and say if you become part of the BIM story that will reduce your variations and change management to a bare minimum, they tell you “… get out of my office! ” because things like change request are how I make my money, how I make my margins because I have to under quote because the competition is fierce. So, if I do not get any changes put in and I charge really good money for those changes, I'm not an even break-even let alone make any margins (Interviewee D).

Promoting or dictating specific collaboration tools was also found to be a barrier to collaboration in BbCNs. According to the interviewees, giant client organisations force project teams to adopt or use specific tools or platforms. As this is seen as an additional cost, it diminishes collaboration, as smaller companies do not have skilled personnel or resources to work with the recommended tools.

## 4.6 Team

The construct *team* was the fifth most significant referred to with 7,233 words (see Figure 3). The interviewees discussed various *team* dimensions that affect relationships among team members and shape their individual team roles with the two most significant being the “BIM Manager role” and the “relationships between teams” (see Table 6).

# Table 6

Teams-related factors and barriers

| Sub-factor | Barriers |
|---|---|
| BIM manager role | Unclear understanding/expectation of BIM manager role and responsibilities |
| | BIM manager has not the full power (PM has more) |
| Relationships | Unestablished collaboration between designers and downstream supply chain |
| | The isolated working mentality of project teams |

It is noteworthy to mention that following interviewees' suggestions, “team composition” from the conceptual model of this study, was modified and merged within the “organisation” barrier, classified under the *context* construct, as discussed.

### 4.6.1 BIM manager role

According to the interviewees, the BIM manager has a crucial role in BIM-enabled projects, with significant influence on project performance and BIM deliverables. In fact, their role entails combining the expertise of various disciplines (including architects, contractors, engineers, project managers and software technicians) to deliver a successful project, so they must have relevant tacit knowledge and experience of all the involved disciplines. Yet, there is little understanding of the BIM manager's role and responsibilities in the industry. This has significant impacts, not only upon project performance but also on collaboration activities:

… [BIM manager] is quite a unique skill and I do not think it's fully defined and I doubt there's a course to support that and by its very nature as the technology evolves so quick and it's a people role it would be hard to put a curriculum even to train for that yet (Interviewee F).

Another barrier to collaboration in BbCNs was found to be the limited power of BIM managers on BIM-adopted construction projects. According to interviewees' perceptions, in some instances, project managers are mainly responsible for preparing the BEP and defining the BIM manager's role and responsibilities and later monitoring and controlling the BEP, as well as the BIM manager. This approach fails to embrace the BIM managers' expertise at the outset of the project and also reduces their power and influence significantly.

### 4.6.2 Relationships among teams

According to the interviewees, the unestablished collaboration between designers and downstream subcontractors and supply chain is a significant barrier to collaboration in BbCNs. Design teams prefer to have less collaboration with other project teams and frequently fail to release design documentation, which is in contrast to the very nature of BIM in which all project teams must be integrated and share information instantaneously:

… though we have CDE in our projects, architects are very reluctant to upload their drawings saying it's still work in progress, and that hinders and slows down the whole process … (Interviewee D).

By the same token, the isolated working mentality of project teams presents another barrier to effective relationships and eventually to collaboration in BbCNs. The number one priority of project teams is to look after their own firms rather than other project teams, where each organisation has its own financial targets and goals that will be achieved through its own members.

## 4.7 Task

Analysis interviews indicated that the *task* construct is the sixth most significant factor affecting collaboration in BbCNs, with 5,666 words referring to it (refer to Figure 3). According to interviewees, this construct has two major dimensions of “demands” and “task structure”, as tabulated in Table 7.

# Table 7

Task-related factors and barriers

| Sub-factor | Barriers |
|---|---|
| Demand | Absence of the right information at the right time to complete BIM tasks |
| | Pressure and tight scheduling imposed by senior managers and/or contractors |
| Structure | Complicated nature of BIM tasks |

### 4.7.1 Demand

Interviewees agreed that the absence of the right information at the right time to complete BIM tasks is a barrier to collaboration. That is, teams usually allocate tasks to their members and other teams involved in the project, however, the correct information needed to ensure proper completion of the tasks (based on desired requirements and time) is missing. Moreover, team members often do not have a clear understanding of the requirements of their assigned tasks because they are not involved in consistent and ongoing communication with senior members of their teams or with members in other teams:

… when starting with the design process, there's sort of a lack of understanding of what we need or [what] the requirement or the task is (Interviewee J).

Interviewees also believed that the pressure of tight scheduling imposed by senior managers and/or contractors represents a further barrier. They believe that this issue is common within sub-contractors' teams and often creates significant problems for collaboration, as members are under pressure to complete their tasks faster than the allocated time-frame. A predominant reason for this is that sub-contractors prefer to complete their tasks in a shorter timeframe in order to sign another contract for another job, and therefore efficient communication and collaboration are of secondary priority.

### 4.7.2 Structure

The complicated nature of BIM tasks was noted as a significant barrier to collaboration performance. Interviewees believed that unlike traditional projects, BIM-enabled projects are governed by complicated regulations and standards regarding BIM models. This extra level of complexity affects collaboration activities. Interviewee F and B commented that:

… there are lots of standards like COBie, Army Corps, and NBS, and the list goes on Each one of those is really quite tricky and it makes it hard to get common and quality communication for the task and requirements, in my observation, and that bolds the task structure, which is, super complicated. Like if you stop and think there was never an official 2D global CAD standard for things like line styles and line weights, however, all that stuff in BIM there is exponentially more variables (Interviewee F).

Contents in BIM models are sourced from different disciplines. For example, you might know the Camel software for calculating HVAC loads. It's like a spreadsheet for calculating heating and cooling loads. Though REVIT and some of these BIM authoring tools also allow you to do that within the software, but the industry is still using both, thus it makes the tasks even more complicated (Interviewee B).

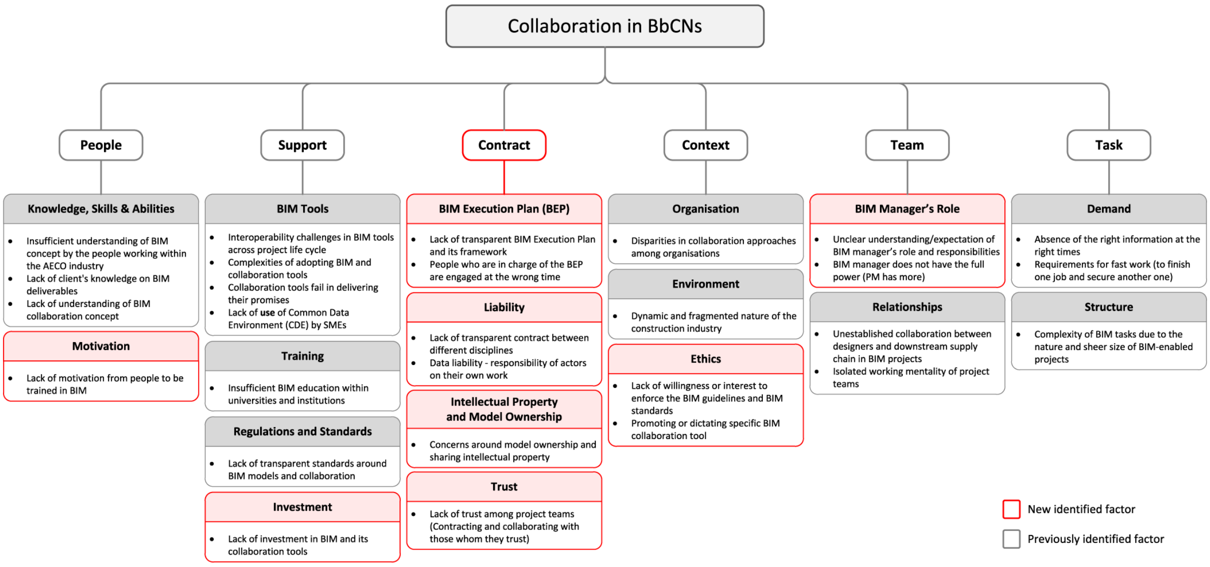
# 5. Discussion of findings

The outcome of the qualitative analysis which modified the conceptual model of the study (see Figure 1), resulted in an integrated model of collaboration in BbCNs, customised and contextualised for BIM-enabled projects, as illustrated in Figure 4. This model demonstrates: (1) newly-identified constructs and factors that act as barriers to collaboration in BbCNs; (2) the associations between collaboration in BbCNs and its major constructs and (3) the association between major constructs and factors/barriers that affect collaboration in BbCNs. From a broader perspective, Figure 4 lends revealing insights into the nature of barriers to collaboration in BbCNs, a description of which follows.

Oraee, M., Hosseini, M.R., Edwards, D. and Papadonikolaki, E. (2021), "Collaboration in BIM-based construction networks: a qualitative model of influential factors", Engineering, Construction and Architectural Management, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/ECAM-10-2020-0865

## Figure 4

Qualitative model for collaboration in BbCNs




As demonstrated in the model (Figure 4), the contractual aspect of collaborative working was found to be a major factor influencing collaboration in BbCNs and comprised of four sub-factors: (1) BIM execution plan (BEP); (2) liability; (3) intellectual property (IP) and BIM model ownership and (4) trust. Other new factors such as ethics and motivation that were identified, though defined under different categories, can also be addressed through the change of underlying contractual arrangements that govern and administer the way members in BbCNs can engage in completing BIM-related tasks.

It can be inferred from the model that collaboration in BbCNs is diminished, largely due to various dimensions such as BIM manager role, BEP, liability, intellectual property, model ownership and motivation that cause a lack of willingness for project team members to engage in inter-organisational or inter-disciplinary activities. This mainly stems from problems founded on unfavourable contractual arrangements (Chan *et al.*, 2019) that fail to: secure the interests of team members; clearly outline their responsibilities and liabilities and assist them in sharing risks, rewards and benefits from project success. The necessity of changing contractual arrangements has been identified in previous studies (Abd Jamil and Fathi, 2018); however, the indirect impacts and potential solutions are hitherto overlooked. The contractual discourse associated with collaboration in BbCNs has remained restricted to the legal domain, disconnected from people and technology dimensions that control BIM-enabled projects. The future of scholarly discourse on enhancing collaboration in BIM-enabled projects must focus on adopting technologies and novel forms of contractual arrangements that foster the willingness of team members to collaborate. The toolsets and enablers of such objectives are available in other industries and can be adopted and adjusted to address the needs of BIM-enabled projects. Recent studies particularly point to the necessity of establishing transparent relationships and interactions as a remedial solution to make people comfortable with exchanging data and providing information. The solution must be a new technology that makes all team members confident that all interactions are secured and effectively protected (cf. Elghaish *et al.*, 2020). Blockchain is proven reliable in making relationships and interactions trustworthy (Turk and Klinc, 2017) hence increasing the chance of collaboration among team members. It is indeed suggested as a solution for shifting to integrated project delivery (Elghaish *et al.*, 2020) and addressing the lack of collaboration due to mistrust among team members of BIM-enabled projects (Mathews *et al.*, 2017). That is because, blockchain has the potential to revolutionise different aspects of a contractual arrangement (Dolgui *et al.*, 2019); it is a distributed ledger that has the advantage of decentralising the operation across the network, where all data are presented as blocks which will be immutable once joined to the chain; and self-authentication is required for all newly recorded data (Elghaish *et al.*, 2020). It is also a platform to execute the so-called "smart contracts" as transactions (Hofmann *et al.*, 2018), a digitalised set of agreements between firms in the form of smart contracts (e.g. designers, engineers and contractors in a design and construction chain), represented in a code and being self-executed by computers once certain conditions (e.g. completion of a task or a BIM deliverable) are met. The application of blockchain has proven effective in enhancing collaboration in particular areas of BIM-enabled projects like financial management (see Elghaish *et al.* (2019)). In summary, the findings of the study indicate that contractual concerns present a major barrier to collaboration in BbCNs and in view of the findings of previous studies blockchain is an ideal solution to address the issue.

# 6. Conclusion

Although a few studies have defined collaboration in BIM-enabled projects as their focal point, the study presented here is the first systematic effort in identifying the barriers to collaboration in BIM-enabled projects, based on empirical data. Original views, new insights and trends emerged as the outcome of this study, encapsulated in the form of a model of factors and barriers that affect collaboration in BbCNs, as the first empirically validated model of its kind. Examination of the model reveals that while most of the major factors to collaboration in BbCNs are presented in previous studies, some act as the root causes of a lack of intention to collaboration in BbCNs. They must be given top priority, that is, they nurture a wide range of barriers to collaboration in BbCNs and addressing them can enable project managers to eliminate the underlying reasoning behind the lack of collaboration in BIM-enabled projects. A clear message relates to proposing a way forward that will address the barriers of collaboration, relying on technological innovations to revolutionise the contractual arrangement of BIM-enabled projects, as a result of which people will be more willing to collaborate and engage in collaborative activities.

The theoretical contribution of this work lies in making clear the underlying problems that diminish collaboration in BbCNs and the potential solutions: relations among inter-organisational collaboration, contractual aspects, blockchain and smart contracts.

The practical implication is that project professionals in BbCNs are called to allocate resources to improve the contractual arrangement and eliminate the underlying causes of team members' unwillingness to collaborate. This involves giving priority to addressing the issues revolving around trust, IP and liability, with better technology.

# 7. Limitations

Despite the contributions, the study's findings must be viewed in light of several limitations. Chief among all is that the interviewees in this study were based in Australia hence their perceptions of collaboration barriers are reflective of the sociotechnical setting of BIM-enabled projects in this country. Direct application of findings of the study to other contexts must be treated with caution. Future research studies to validate and compare findings with data acquired from other countries and a broader range of experts including owners, developers and all influential stakeholders can extend the findings of the present study. Besides, findings are based upon experts' perceptions, rather than analysis of performance measures or quantitative assessment of associations among collaboration outcomes and various factors. This, however, provides the field with fertile grounds for future research. Future studies can assess the applicability of findings in other countries and contexts, propose solutions for addressing the identified barriers and their root causes and define methods to assess collaboration in BbCNs based on hard data and quantitative methods. Moreover, the suggestion of the present study for using blockchain as a remedial solution to contractual concerns – to enhance collaboration – is not validated through data in a broad scale of the industry, though this suggestion has support from previous studies in case projects. This remains a topic to be explored in future research studies.

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