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BIM Collaborative Design: A Critical Perspectives of Technology-Supported Multidisciplinary Practice

Danfulani, Babangida Idi[1]*, Khairul Anwar Mohamed, Khaidzir[2] and Ibrahim Sani Khalil[1]

[1]Department of Architecture, Faculty of Earth and Environmental Sciences, Bayero University, Kano.

[2]Department of Architecture, Faculty of Built Environment and Surveying, University of Technology Malaysia.

Corresponding Author: bidanfulani.arc@buk.edu.ng

ABSTRACT

Building Information Modelling (BIM) collaborative design provides a platform where all stakeholders work on one single building information model embedded with multiple digital data points for the production and construction information of the building. The platform uses hyper-computer-mediated software for functions like fabrication, assembly, animation, analysis and simulation that are generally referred to as authoring and analysis for integrated project delivery (IPD). No doubt, issues of BIM collaborative design are well established in the literature of technology-supported multidisciplinary practices such as system applications and technologies; information and data management; multidimensional ecosystems and media interactions; and scientific strategies of practice. However, grounded conceptual and conventional design and collaboration requirements are not clearly and adequately represented. Therefore, this study reviewed core design collaboration research articles using content analysis to establish the theoretical framework BIM collaborative design and subsequently established its strength and challenges. 156 out of the 176 published materials on design collaboration from 1950 to date from ScienceDirect under the licences of Bayero University, Kano and Universiti Teknologi Malaysia were selected and reviewed. In addition to the already established BIM collaborative design parameters, the content analysis revealed that; group cognition (cognitive actions and reasoning), knowledge exchange, lateral and vertical transformations were also found relevant in the theoretical framework of BIM collaborative design. The logical argumentation showed that studies on the tacit knowledge problem-solving space such as experience, skills, know-how, group cognition, knowledge transformation; assets and 'ba' are missing in the literature of the BIM framework of collaborative design. Thus, this study concludes that, even though BIM collaborative design has been globally accepted, there is a need to extend its research and support in tacit knowledge problem-solving spaces.

Keywords: BIM, Collaboration, Design, Problem-Solving, Tacit-Knowledge

INTRODUCTION

According to Idi and Khaidzir (2018), collaboration in the Building Information Modelling (BIM) framework is defined as a process in which different actors collaboratively manage the design and construction information of a building. The collaborative process is guided by system applications and technologies that will allow the sharing of information and data using a multidimensional ecosystem and media of interaction under specific practice strategies. The framework provides a platform where all stakeholders work on one single building

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information model embedded with multiple digital data points for the production and construction information of the building. Hyper-computer-mediated software platform functions like fabrication and assembly are referred to as BIM authoring (Garber, 2014); animation and simulation are referred to as BIM analysis (Garber, 2014). The authoring and analysis approaches jointly provide virtual information processing and management for integrated project delivery (Mitcham, 1995). The majority of the literature is inclined towards Integrated Project Delivery (IPD) as the major function of the BIM framework of collaboration due to its ability to allow stakeholders the opportunity to virtually identify and resolve issues and clashes during design, construction, and post-occupancy (Garber, 2014; Vaishnavi and Kuechler, 2015; Preece et al., 2015; Hardin and McCool, 2015). In summary, the BIM framework of collaboration in design consists of the following parameters: system applications and technologies; information and data management; multidimensional ecosystems and media of interactions; and strategies of practice.

LITERATURE REVIEW

This section presents a literature review on the Building Information Modelling (BIM) framework of Collaboration in the Context of Design.

The Definition of Collaboration

Theoretically, the term collaboration has a Latin origin, in which "com and elaborate" merge to form collaboration. Based on the Latin meaning, collaboration means two or more people working together. Most theories on collaboration stress the understanding of collaboration as the process of working together among people. However, there is still no established definition of what design collaboration is theoretically, its frame or its parameters. The answers are presented in the following paragraphs and subsections:

From a theoretical point of view, Appley and Winder (1977) define collaboration as relationship in which the parties care for and are committed to each other as the major component of collaboration. Gray (1989) defines collaboration as a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible. Sharfman and Dean (1991) define collaboration as a process of joint decision-making among key stakeholders of a problem about the future of their domain. Nathan and Miitroff (1991) described collaboration as a group of key stakeholders who work together to make joint decisions about the future of their problem domain. Roberts and Bradley (1991) described collaboration as an interactive process having a shared transmutation purpose and characterised by explicit voluntary membership, joint decision-making, agreed-upon rules, and a temporary structure. Roschelle and Teasley (1995) defined collaboration as human participation that helps achieve a collective solution for a single problem. Smith and Katz (2000) defined collaboration as a shared environment, media, and goal that goes beyond coming together to form a relationship for gain and benefit. Roschelle and Teasley (1995) explained that the activity constructs and maintains a shared conception of collaboration. Dillenbourg et al. (1996) viewed collaboration more specifically as team activities that create the mutual shared engagement of participants in a coordinated effort to achieve a common goal. Kahn (1996) found that the bond that creates a common mutual vision and outcome distinguished collaboration from other forms of teamwork such as cooperation, networking, coordination, coalition, and learning. Baud et al. (1999) defined collaboration as a valuable and efficient problem-solving process, that is, rich in learning, innovation, and organisational development.

Hocevar et al. (2011) defined collaboration as a medium with the capacity for addressing shared problems or achieving a shared goal at an inter-organisational and community level. Kotlarsky and Oshri (2005) considered social ties and knowledge sharing as the major factors for successful collaboration in globally distributed system development projects. Uzzi and Spiro (2005) defined collaboration as a process that yields a better outcome when compared with the work of a loner, which is more suitable for solving problems than individual work. According to Stahl (2006), collaboration is when individuals, groups or organisations work together to achieve a defined common goal. Kleinsmann (2006) stressed that shared environment, media, and goal are the typical distinguishing components of collaboration from cooperation, networking, coordination, coalition, and learning. Patel et al. (2012) used context, team and strategy as three major factors that constitute a collaboration. It can be seen that, based on the literature definition of collaboration so far, collaboration has been differently explained.

However, four basic characteristics of collaboration emerged namely; shared goal, team, environment, media and knowledge. Thus, this study has summed up all the theoretical views and defined collaboration as a process through which a team shared their differences, environment, media and knowledge to constructively search for a common goal that is beyond individual vision (Hord, 1986; Gray, 1989; Wood and Gray, 1991; Mattessich and Monsey, 1992).

Literature Perspectives on BIM Collaborative Design

McCall and Johnson (1997) produced what was considered the first milestone digital tool that supports shared communication in the context of design using argumentative agents, namely the PHIDIAS hyper-CAD system that supports the sharing of times and places during collaboration. Schmitt (1998) developed a tool for engineers and architects using conventional and AI communication systems to support the large distribution of data among multiple users during design. Other comparative studies on BIM-based collaborative design using a computer-mediated shared environment on designers' freehand drawing environments during long-term distributed interactions include Johansson and Popova (1998), Jeng and Eastman (1998), Kalay (1998), Kalay et al. (1998), Veeramani et al. (1998) and Gross et al. (1998). Yan-chuen et al. (2000) established a significant difference between active and passive model-making in two shared environments. Gabriel and Maher (2000) found that the use of computer-mediated media does not necessarily mean emulating close proximity between face-to-face (FTF) and virtual communication (video conferencing). Cheng and Kvan (2000) and Kvan (2000) established a shared strategy for technology-supported environments. Rosenman and Wang (2001), Tang and Frazer (2001) and Woo et al. (2001) established that collaborative work progresses smoothly between participants in the multi-user workspace. Kalay (2001) provided a frame-of-reference to resolve issues of misunderstanding during collaboration in design. Austin et al. (2001) successfully tracked and framed the iterative nature of the conceptual design activities.

Chiu (2002) established that the team organisation structure is a factor of better communication in collaborative design. Craig and Zimring (2002) found that an Immersive Discussion Tool (IDT) allows more 3-D model reasoning over the Internet using view-dependent and view-independent diagrammatic marks, dynamic simulations, geometric design surrogates and text annotations. Craig and Zimring (2002) established that internet-based and VRML Java-based shared media significantly influenced verbal and graphical communication. Gabriel and Maher (2002) supported the idea that computer-mediated collaborative design does not necessarily mean emulating communication in close-proximity environments. Stempfle and Badke-Schaub (2002) proposed a two-process theory of thinking in design teams in affirmation of the theory of the psychology of human information processing and decision-making. Achten (2002) supported the need for computer-aided design tools that support the virtual environment. Cheng (2003) identified that the tangible user interface shared environment has a strong potential for innovations. Garner and Mann (2003) found that computer supported collaboration work (CSCW) systems improved project management information exchange among team members. Lahti et al. (2004) found that coordination, cooperation, and collaboration are key characteristics of the environment in which designers tend to be more collaborative during the conventional process. Maher et al. (2005) integrated 3D virtual worlds and CAD systems using a common data model to develop a multi-agent virtual design shared media system (MAVDCS) that allows active data sharing. Chen et al. (2005) also developed and implemented an IFC-based web server for building a shared environment between architects and structural engineers.

Dong (2005) revealed that similarity of language supports indirect relations among components of designers' tacit knowledge in the constructed shared mental representation of the designed artifact. Plume and Mitchell (2005), Rosenman et al. (2007), Han et al. (2006) and Wang and Dunston (2008) found that the mixed reality tool facilitates effective problem-solving patterns. Gul and Maher (2007) identified some similarities and differences between face-to-face sketching media and remote designing using virtual media. Kan and Gero (2010) found that 3D media encourage a loosely coupled design process. Isikdag and Underwood (2010) proposed a system using the BIM-based approach to facilitate a shared environment for the entire lifecycle of the building. Chung et al. (2009) improved the efficiency and reliability of shared environments during project briefings for ICT based megaprojects. Dave and Koskela (2009) established a means of using information and communication technologies to offer some solutions to implement knowledge management solutions in a shared environment. It can be seen that the extensive review so far shows that most of the studies still focused on virtual and real-life environments, internet, computers, and technology supported tools. However, very few of the reviewed studies so far have researched what, when, why and how to collaborate while designing. What strategies and actions facilitate designing collaboratively in a shared environment have not been investigated. Therefore, this highlighted a possible future research question.

Kan and Gero (2010) compared the behaviour of designers in a shared 3D virtual environment with those in a real face-to-face shared environment using quantitative tools. The study found that the 3D environment increases the designer's rate of meaningful communication (structure activities) over the real F2F shared environment. However, the

VR 3D environment proved otherwise when Rahimian and Ibrahim (2011) studied the impacts of VR 3D sketching on novice designers' spatial cognition in conceptual architectural design. The study found that conventional computer-aided design tools lack intuitive design activities, whereas VR 3D sketching was found to have a significant impact on novice designers' cognitive actions for design creativity. Gu et al. (2011) compared shared environment technologies for architectural design, like the effect of 3D virtual media and tangible user interfaces (TUI) on architectural design collaboration. The study has successfully identified and established some key recommendations for the future development of shared mixed media technologies for shared architectural design. Ren et al. (2011) also recommend multi-agent systems shared environment for optimising shared environment approaches to design.

Xue et al. (2012) present a comprehensive ten-year literature review (2000–2009) on the implementation of IT in a shared environment. Rahman et al. (2013) compared the manipulation of 2D-objects in synchronous and asynchronous distributed shared environments. The study uses changes in the usage of the shared object across design phases in the distributed shared environment. The findings of the study support clear indications of phase-specific usage of the shared object in the synchronous setting. The two settings also show varying usefulness depending on the design stage indicating the disparate impact of synchronous and asynchronous settings on collaboration quality in disparate design phases. Lee and Jeong (2012) found that due to disciplinary differences among the participants, the user-centric knowledge representations of the collaboration in design failed. The failure is due to a lack of understanding of the nature of multi-disciplinary design and the lack of tools that can support it. The study established a suitable model for a machine-mediated tool to support knowledge representation in multidisciplinary collaboration in design.

Following the above discussions, to the best of the researcher's knowledge, it can be seen that only two studies have been conducted on knowledge in design teams. The first is the study of user-centric knowledge representations of collaboration in design by Lee and Jeong (2012). Ren et al. (2012) used a performance measuring matrix to measure the strength and weakness of communication activities in the shared design environment. The study summarised the strengths and weaknesses of a shared design environment and also suggested suitable responsive actions for improving communication activities in collaboration in design. Senette et al. (2013) reported the proposal of a method for the design of an adapted visualisation for the 4D applications shared environment. Also, Fernando et al. (2013) developed a virtual shared environment to support collaboration in design review meetings.

Another study by Wiltschnig et al. (2013) analysed problem solution co-evolution in creative collaboration in design. The outcome revealed that co-evolution episodes occurred regularly and embodied various directional transitions between problem and solution spaces (creative activities). It affirmed the view that co-evolution is the mechanism of creativity in design collaboration.

Eris et al. (2014) compared multi-media communication during distributed design sessions. Based on a comparative analysis of sketching in co-located and distributed environments, it was established that when gesturing reduces, graphical communication increases and vice versa, and that verbal communication is continuous in both environments. Wang et al. (2014) also established that BIM-enabled complex building shared environment technology significantly shortened design time and improved design performance. Skopp et al. (2015) analysed distance shared media (DSM) which was found to be a reasonable alternative to meeting face-to-face. Hong et al. (2016) investigated the enablers and barriers of multi-user virtual media (MUVM) and sketching media in face-to-face and remote collaborations. The study found that co-presence in the sketching medium promotes emerging creative solutions, while the MUVM does not enable creative solutions. Finally, the study confirmed that most of the past studies have concentrated on the efficiency of shared digital media. Neghab et al. (2015) measured the performance evaluation of collaboration in the design process using interoperability measurements. Kasali and Nersessian (2015) observed that architects allowed distributed disciplinary expertise to morph into a new form of interdisciplinary expertise to solve problems in situ. Leon et al. (2015) demonstrate technologies of communication for conceptual design protocols for pre-BIM stages. Luyten (2015) studied CAAD and the conceptual shared environment between architects and structural engineers. Oh et al. (2015) developed an integrated system for the BIM-based shared environment. BIM also provides the evidence-based design practice (McMillan and Schumacher, 2010; Fruchter, 2003; Zolin et al., 2004). Evidence-based design (EBD) practice is another contemporary strategy that supports collaboration during design problem-solving through publications, conferences, seminars, and workshops. According to Gu et al. (2011), the Graphical User Interface (GUI), Tangible User Interface (TUI), Virtual Reality (VR) and Augmented Reality (AR) can support different time and place interactions in a real-life situation or a virtual one.

It can be seen that the BIM framework seems to have an information-based purpose and goal, a multidisciplinary-based membership role, a digital-oriented environment and modalities, and an explicit knowledge problem-solving space orientation. However, grounded design conceptual purpose and goals are uni-disciplinary in nature and are attached to conventionally oriented environments, modalities, and problem-solving spaces, are not found in the BIM literature.

MATERIALS AND METHODS

The methods used in this research are content analysis and logical argumentation (Chai and Xiao, 2012; Pilkington and Chai, 2008; Cross, 2000; Groat and Wang, 2013). 179 articles on collaboration, design collaboration, and the BIM framework of collaborative design were selected and used for the content analysis. Citation was not used as a criterion for the selection. Only their focus and relevance to the subject matter were considered. The content analysis provides the literature-based constituents of collaboration in design. Whereas logical argumentation on the different explanations will identify design constructs and also highlight some research gaps and missing links. Both methods can potentially lead to design variables for the BIM framework of collaboration in design.

RESULTS

This section presents the outcome of the content analysis. One hundred and seventy-nine (179) published materials were downloaded from ScienceDirect under the licences of Universiti of Technology Malaysia and Bayero University, Kano, for the study. Out of which, one hundred and fifty-six (156) were selected based on their relevance to the intended study. The content analysis revealed four (9) themes from the published materials (refer to Table 1.0). Table 1.0 below presents the results according to themes.

Table 1: Theoretical framework of BIM collaborative design constructs.

Sno.	Authors & Year	Theme(s)	BIM Collaborative Design Constructs
1	Kvan (2000), Kvan et al. (1997), Vera et al. (1998), Maher et al. (1998)	Nature	Mutual Exclusive Authoritarian
2	Dillenbourg (1999), Andersen and Wagenknecht (2013), Defila and Di Giulio (1998), Holbrook (2013), Klein (2010), Schmidt (2013), Schmidt et al. (2014), Day et al. (2005), Alkaslassy (2011), Taylor et al. (1979), Simmel (1950), Mueller (2006), Rothbard (1998), Wittenberg-Lyles (2005).	Task	Conceptual Schema Technical
3	Chui, (2002), Danfulani and Khaidzir (2015), Idi et al. (2011), Idi and Khaidzir (2011), Perry and Sanderson (1998), Dennis and Valacich (1999), Klemmer et al. (2008), Robert and Dennis (2005), Dennis et al. (2008), Rogers et al. (2009), Dorta et al. (2011) Geyer et al. (2001), Gu et al. (2011) Gumienny et al. (2011), Shen et al. (2010), Klemmer et al. (2008), Kvan et al. (1997), Dennis and Kinney (1998), Robbins (2001), Schon (1987), Gorse and Emmitt (2007), Lengel and Daft (1984), Sproull and Kiesler (1991), Stahl (2006), Boud et. al (1999), Preece et. al (1994), Huxham (1996), Goldschmidt (1995), Hord (1986), Bafoutsou and Mentzas (2002), Wiegeraad (1999), Rahman et al. (2013), Gu et al. (2011).	Environment	Synchronous Asynchronous
4	Ringlemann (1913), Simmel (1950), Derlega and Chaikin (2007), Taylor et al. (1979), Day et al. (2005), Alfano (2014), Alkaslassy (2011), Eppler and Sukowski (2000), Mueller (2006), Lim and Klein (2006), Mueller (2006), Wittenberg-Lyles (2005), Klein (1987), Milliken and Martins (1996), Wittenberg-Lyles (2005), Cooper (2006), AAG (2015), Defila and Di Giulio (1998), Andersen and Wagenknecht (2013), Holbrook (2013), Klein (2010), Schmidt et al. (2014), Schmidt (2013).	Team	Discipline Size Dynamism Cohesion
5	Isikdag (2012), Isikdag and Underwood (2010), Sailer et al. (2009), Danfulani and Khaidzir (2015), Dorst (1997), Goel, (1995), Laseau (2001), Goel (1995), Purcell and Gero (1998), Lawson (2004), Gero et al., (2001), Fish and Scrivener (1990), Robbins (1994), Schon (1983), Goldschmidt and Smolkov (1994; 2006), Lawson (2002), Gross et al. (1998), Do and Gross (1996), Suwa et al. (2001), Krauel (2010), Thrift and French (2002), Pallasmaa (1996), Zumthor (2006a; 2006b), Ash (2010), Klingman (2006), Chi et al. (2013), Irlwek and Menges (2013), Goldschmidt (1991), Schon (1983), Khemlani (2006), Aish and Woodbury (2005), Anderl and Mendgen (1996).	Modalities	Digital Virtual Real-life Sketch
6	Liebowitz (1999) Nonaka (1994), Ibrahim (2005), Ibrahim et al. (2005), Ibrahim and Nissen (2005; 2007), Ibrahim and Paulson (2008), Polanyi (1962; 1966; 1967), Schon (1984), Levitt and March (1988), Yamauchi (2014), Ackoff (1989), Davenport and Prusak (2005), Nonaka et al. (1996; 2001), Nonaka and Kunno (1998; 2001), Nonaka et al. (2000) Prigogine, (1985), Polanyi (1962, 1967), Nonaka (1994), Nonaka and Takeuchi (1995), Nishida (1921), Shimuzu (1995).	Knowledge asset, space and transfer	Experiential, Conceptual Routine Systemic Originating ba Dialoguing ba Systemizing ba Exercising ba Socialization

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			Externalization Combination Internalization
7	Schon (1983; 1984; 1987; 1991), Valkenburg and Dorst (1998), Dorst (1997), Gero and Kannengiesser (2008), Boud et al. (1985), Rowland (1993), Hekkert et al. (2003), Duckett (2002), Boud and Walker (1993), Clancey (1997), Khaidzir and Lawson (2013), Goldschmidt (1990; 1991, 1995, 2014).	Cognitive actions	Naming Framing Moving Reflecting
8	Eckert et al. (2000), Bredeweg et al. (2009), Rowe (1987), Kolko (2010), Peirce (1988), Goodwin and Johnson-Laird (2005), Dorst (1995, 1997, 2006, 2011)	Reasoning	Deduction Induction Deduction
9	Fish and Scrivener (1990), Fish (2003), Goel (1994; 1995; 2004), Goel et al. (2015), Abdelmohsen and Do (2007), Prats et al. (2009), Helmi and Khaidzir (2016), Khaidzir and Lawson (2013), Lawson (1979; 1997; 2002; 2004; 2006)	Transformation	Vertical Lateral

DISCUSSION

The theoretical Framework of BIM Collaborative Design

Based on the literature perspectives of design (Simon, 1969; Simon and Simon, 1978; Schon Based on the literature perspectives presented in Table 1.0, the main collaborative design constructs include nature, goal, team, environment, modality and knowledge space. A summary of the framework is illustrated in Fig. 1.0. At the top of it is the healthy situation, where all the requirements for a successful collaborative design are provided, including BIM perspectives, provisions and approaches. However, the bottom illustrates that if any of the provided constructs fail to be considered or carefully used according to the prescribed literature, then it will lead to a dysfunctional situation that is unhealthful to the process. Although some literature across Europe, Asia and USA indicates that collaboration increases the efficiency of design (Fruchter, 1999; Hussein and Peña-Mora, 1999; Devon et al., 1998; Simoff and Maher, 1997; O'Brien et al., 2003; Holland et al., 2012; El'Asmar and Mady, 2013; Dong and Doerfler, 2010; Karakaya and Şenyapılı, 2008; Fruchter, 2003; Zolin et al., 2004). However, the big question now is whether all the collaboration and design constructs, as shown in Fig. 1, are considered. If not, then issues of design efficiency in a collaborative setting would have to be validated based on theoretical testing and measurement using healthy situations, as shown in Fiure 1. The synopsis of the collaborative design constructs is illustrated in Table 1 and Fig. 1.0 is presented in the subsections below.

Nature: Iterative and non-linear

The nature of BIM Collaborative design is never a mine-or-my alone activity. It involves others from within the same or different professions. Perhaps it is not a linear and incremental process but rather an iterative process where stakeholders work together in discrete steps that require a series of decisions. As presented in Table 1, the nature of collaborative design is to work together for moments, then divide up and go separate ways, and later come together again and continuously, namely: mutual, exclusive, and authoritarian. The mutual collaboration is busy working with each other throughout. The exclusive collaboration is to work on it partially together and separately. The authoritarian is one person who leads the process. It can be postulated that exclusive collaboration is the most effective and the one in which they observed the most productive results, and of course, it is also more suitable for collaboration in design.

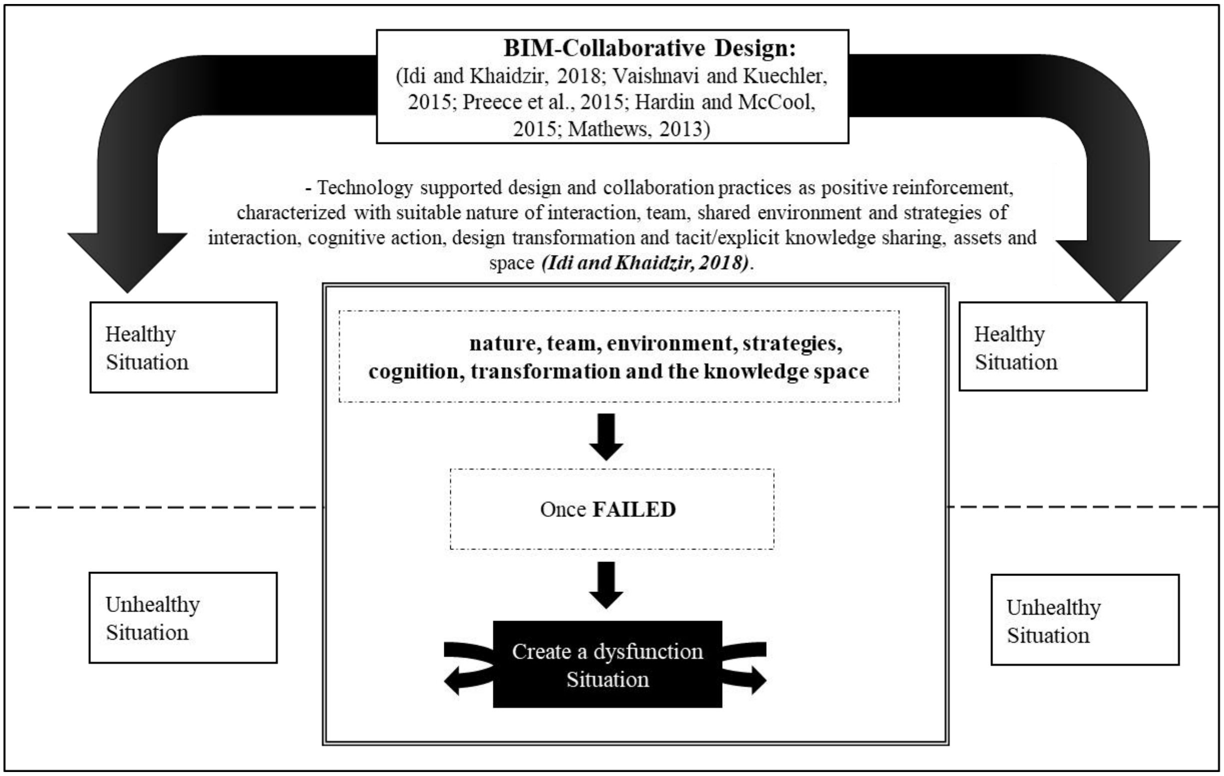

Figure 1: Theoretical framework of BIM Collaborative Design

Task: Goal and Purpose

The task has a common goal, purpose, and desirable outcome. There must be a specific collective design goal from which all other parameters are derived. For example, typical design tasks are connected to conceptual, schematic, or technical tasks, as presented in the second row of Table 1.0.

Environments: Synchronous and Asynchronous

Being a vital process for integrated problem-solving, collaboration can be used in two different environments, which can be synchronous or asynchronous, as presented in the third row of Table 1.0. The two environments distinctively represent the working ecosystem of stakeholders through backtracking, iteration, and feedback. Asynchronous is a time-shifted interaction that is different in time and location, e.g., email messages, audio, and video streaming. Synchronised interaction is real-time and same-time, such as face-to-face brainstorming, chatting, video conferencing, apprenticeship, discussion, dialogue, sharing presentations and information using phones, video links, and face-to-face discussion, and is more efficient.

Team: Properties and Structure

It can be seen that the general literature on collaboration places emphasis on cohesion, openness, learning, and disclosure of inner intentions against the BIM focus on multidisciplinarity and performance (Table 1.0, Row No. 4). For example, the nature of the participants in a team is the main factor that determines the performance of the team, not necessarily the size of the team. Additionally, members who are friends or relatives can become a barrier to understanding the equity of the work done by each member. Triads can easily control their togetherness and exclusiveness during teamwork compared to dyads and large teams. The only three characteristics of a team that can improve team performance are: social loafing skill, free riding, knowledge, and willingness. It can be deduced that individual performance, race and age, numerical minority, communication, and diversity do not support cohesiveness. But the rate of similarity among team members increases performance, coordination, and efficiency, not diversity. On the last note, there is a need to focus on factors that can improve team performance among multidisciplinary stakeholders working together towards a common objective.

Strategies: virtual vs. real, time-shifted vs. face-to-face, digital vs. sketch

Discussions on collaboration have become prominent in present-day research using virtual computer-supported collaborative for virtual and real-life interactions through meetings, conferences, seminars, workshops, and publication.

Knowledge Exchange: Assets, Spaces, and Transformations

Through collaboration, unspoken and uncodified experiences can be shared at the conceptual stage, while things and awareness of context are documented at the final design stage. Considerable knowledge exchange implementation methods such as socialisation, externalisation, internalisation, conceptual assets, and experiential learning are presented in Table 1.0.

Cognition: Actions and Reasoning

Design is supposed to involve multilayers of reasoning and cognitive actions depending on the collective consciousness of a primary experiential knowledge source while making movements and thinking when dealing with problems in design (refer to Fig. 1.0). These will provide a way of thinking to broaden the repertoire of strategies for addressing complex and open-ended problems and challenges. Reasoning is divided into three categories: abductive, inductive, and deductive. Abductive reasoning is the driver of design synthesis through sensemaking, which is the understanding of connections necessary to effectively act.

Transformation: Abstract to Concrete

Visual transformation is a specialised technique used to generate, document, understand, and track design activity and developmental progress. Design progress can be tracked laterally or vertically. The lateral transformation is identified as movement from one idea to a slightly different idea, whereas the vertical transformation is identified as movement from one idea to a more detailed version of the same idea.

Challenges of Tacit Knowledge Problem-Solving Space in BIM Collaborative Design

The extensive review has shown that the majority of the studies on BIM collaborative design focused on the digital-based tools, activities, environment, media and practice guided by highly computerised systems such as AI, VRML Java, 3D-VW, CAD, IDT, MAVDCS, 3D-VRS, TUI, CMCD, DSM, and MUVM, GUI, VR and AR. Among the reviewed literature, no study was found on tacit knowledge problem-solving spaces, an area that was proved to be one of the most important areas for knowledge exchange among individuals, groups or organisations by notable scholars such as Liebowitz (1999),

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Nonaka (1994), Ibrahim (2005), Ibrahim et al. (2005), Ibrahim and Nissen (2005; 2007), Ibrahim and Paulson (2008), Polanyi (1962; 1966; 1967), Levitt and March (1988), Yamauchi (2014), Ackoff (1989), Davenport and Prusak (2005), Nonaka et al. (1996; 2001), Nonaka and Kunno (1998; 2001), Nonaka et al. (2000), Prigogine (1985), Nonaka and Takeuchi (1995), Nishida (1921) and Shimuzu (1995).

These present challenges for the application and support of tacit knowledge problem-solving space, as shown in the red-marked portion of Figure 2, in Idi and Khaidzir (2018), Vaishnavi and Kuechler (2015), Preece et al. (2015), Hardin and McCool (2015), Mathews (2013) BIM technology-supported collaborative design. This undermined the designer's performance and intellectual representation, which can lead to the impediment of important constructs contained in the red marked portion of Figure 2.

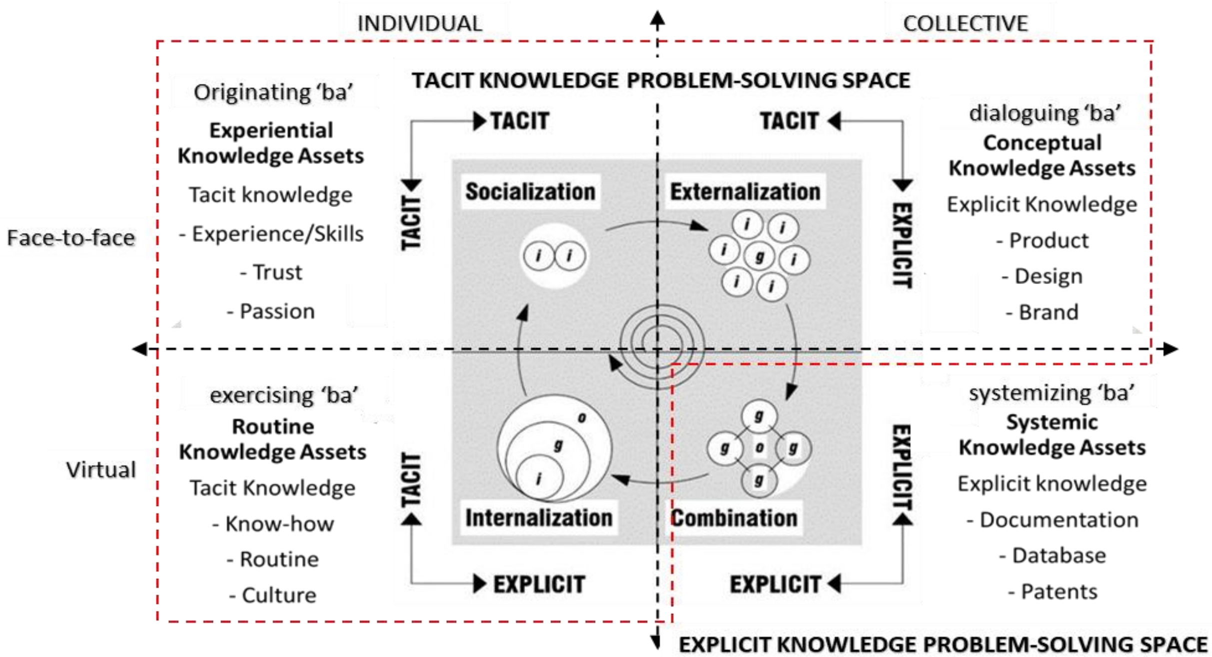

Figure 2: Tacit knowledge problem-solving spaces in red demarcation (Nonaka and Konno, 1998)

Thus, there is a need for empirical research on issues of tacit knowledge problem-solving space such as socialisation, experience, skills, trust, passion, externalisation, brand, internalisation, know-how, culture, framing, reflection, abduction, induction, experiential knowledge asset, conceptual knowledge asset, routine knowledge asset, originating ba, dialoguing ba, and exercising ba in the BIM collaborative design. This gap has also been acknowledged in earlier studies as a limitation of the BIM framework with regards to giving due consideration to conventional practices (Lee and Jeong, 2012; Gul and Maher, 2007; Kan and Gero, 2010; Nepal and Staub-French, 2016; Dossick and Neff, 2011; Ewenstein and Whyte, 2009; Wang and Meng, 2019; Hossam et al., 2021; Ganiyu, 2020).

The explicit Knowledge Strength of BIM Collaborative Design

On the other hand, literature on the BIM framework of collaborative design was found to be more oriented towards the explicit knowledge problem-solving space. This shows that the majority of BIM collaborative design research directly focuses on schematic and technical designs that are physically accessible or expressible as audio-visual data, drawings, figures, and any form of information that is physically and visually descriptive and can be stored, transferred, modified, and communicated to an audience even if geographically separated (Idi and Khaidzir, 2018; Vaishnavi and Kuechler, 2015; Preece et al., 2015; Hardin and McCool, 2015; Mathews, 2013). A typical example of explicit knowledge space is illustrated in the lower left quadrant of Fig. 2.0, which includes combination, systemic knowledge assets and systemizing ba.

Furthermore, the explicit knowledge dominance of BIM collaborative design research also concurred with the outcomes of other studies. Notable among them are Nepal and Staub-French's (2016) proposed strategies for supporting knowledge-intensive construction management tasks in BIM. Dossick and Neff (2011) messy talk and clean technology in BIM-based collaboration. Ewenstein and Whyte (2009) impact of knowledge practices on the role of visual representations in collaborative design. Wang and Meng (2019) IT-based BIM-supported knowledge management model. Hossam et al. (2021) interdisciplinary approach for tacit knowledge communication between the designer and the computer. Ganiyu (2020) and Wang et al. (20) examine the boundaries and improvements of BIM knowledge-based practices in building construction.

CONCLUSION

Finally, it can be concluded that, even though, BIM has demonstrated a global acceptance that offers optimal improvement in almost all ramifications of the building construction ecosystem, issues of designers and allied professionals human attributes are seldom discussed in the BIM framework. Therefore, this article strongly recommends and suggests that there is a need to extend research investigation under the BIM framework to cover problem-solving spaces such as socialisation, externalisation, and internalisation, experiential and conceptual knowledge assets, and originating and dialoguing ba's.

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