

## Review Article

# Mapping Knowledge Domains of Integration in BIM-Based Construction Networks: A Systematic Mixed-Method Review

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Building information modeling-based construction networks (BbCNs) are teams from several professional organizations working together to assume building information modeling- (BIM-) related assignments on BIM-enabled projects. With a view to achieving a better understanding of the knowledge domains on integration in BbCNs, a systematic mixed-method review of the relevant studies published from 2008 to 2018 is conducted in this study. An “integration pentagon” made up of context, process, organization, task, and actor is used as a theoretical lens to identify and construct knowledge maps describing the integration in BbCNs. The study conducts a comprehensive review upon a bibliometric analysis based on 1019 researches into BIM and a qualitative analysis of 42 carefully selected researches into integration in BbCNs. The findings confirm that the solutions provided by these researches to support integration in BbCNs are altogether technology oriented. The sociotechnical dimensions including context, organization, task, and actor show limitations. More importantly, the major academic contributions of the study lie in offering an objective and systematic analysis of previous researches, revealing the gaps on integration in BbCNs, and advising researchers in future studies regarding the integration pentagon as an all-inclusive analysis tool. These results highlight the status quo of BbCNs knowledge and serve as a dynamic platform to allow other scholars to perform further developments of integration in BbCNs.

## 1. Introduction

Applying building information modeling (BIM) in delivering construction projects has been on the rise [1, 2]. BIM-enabled projects are delivered through using building information modeling-based construction networks (BbCNs), defined as teams comprising specialist organizations that are contracted to execute BIM-related works on these projects [3]. The capability to increase integration in these BbCNs has been essential BIM [4]. Nevertheless, sustaining integration among members with geographic dispersion from various organizations and disciplines within BbCNs has been regarded to be problematic [5, 6] and thus consequently deserving further exploration.

Although the existing research underlines the importance of integration and explores the factors impacting

integration in BbCNs [7], the insufficiency application status of integration in practice still makes reference to the gaps in the body of knowledge (BOK) on integration within BbCNs [5, 8, 9]. At the stage, there is an absence of BOK on integration to guide its development in BbCNs, although Oraee et al. [10] have researched the collaboration in BbCNs. However, it should be emphasized that from the point of view of project management research, the meaning of “collaboration” and “integration” is not consistent, and the “integration” means the synergy of internal systems in a separate unit (that is, the project), which is more responsive to the characteristics of the project [11, 12]. BbCN is a construction network built from a project-based unit, and it is more necessary to study its integration characteristics. This discovery induces a great obstacle in determining the direction for research on integration in BbCNs, which

make it difficult to capture frontier highlight or repetitive efforts.

Accordingly, it is urgent to integrate the existing literature, which might fill the gap and indicate future research highlights [13]. To this end, we draw on the research method of the article of Oraee et al. [10] which was published in the *International Journal of Project Management (IJPM)* in 2017 and analyze the scholarship on integration in BbCNs. In addition, unlike the study of Oraee et al. [10], this research provides an extended version of an extended Leavitt sociotechnical model as the theoretical point to map and analyze the status of existing literatures on the integration in BbCNs. The results are likely to grasp the connotation and characteristic of integration research in BbCNs and reveal the concepts and patterns which have been maintained hidden on this topic. Moreover, the findings will play a positive role in guiding and promoting theoretical research and practical application in this field.

The paper starts with a brief explanation of integration within BbCNs, which is followed by the research method. Research findings are then outlined. In the subsequent section, a discussion of those findings is introduced. The paper folds with a summary of the major points and conclusions.

## 2. Background

*2.1. Integration on Construction Projects.* Integration refers to the process of integrating isolated elements or things into an organic whole. The concept of integrated management was first proposed and applied from the information technology (IT) industry and later developed into a field of expertise in project management. In this new management concept and method, integrated concepts are leveraged to guide and manage practical activities [14]. A traditional management mode derives from the theory of division of labor, while this new approach highlights integration thought, and it also fuses and amplifies individual advantages so that improved comprehensive efficiency, along with management activities, is ensured.

An integrated implementation relies on close communications between project participants [15–18]. With the occurrence of CIM (computer integrated manufacturing) propagation and applications of IT into construction activities [19], the essence of integration has experienced a thorough variation over the past few years [20, 21]. In nature, BIM has evolved into the core of cross-organization integration technology to support integration of participants [22]. As BIM is developed into a state-of-the-art technology to facilitate integration in the construction industry, BbCNs appear as a major carrier to foster integration [2, 5, 9] as described below.

*2.2. BIM-Based Construction Networks (BbCNs).* BIM is a solution to multiparty coordination of innovative technology, and its value depends on a rational organization pattern. Solihin et al. [23] even believe that the traditional project organization model fails to make BIM meet project

requirements. Under such circumstances, scholars recognize the necessity of studying the cross-organization application of BIM and putting forward the BbCNs [2]. As BbCN is proposed, construction projects have essentially transitioned to “temporary social networking organizations,” [24] indicating that project participants are exposed to a new integration environment. The attainment of the goal and success in BbCNs depends on a closely integrated working and seamlessly information sharing of participants [19, 25–27]. Therefore, many scholars emphasize that we should cultivate the integration environment to transform our traditional ideas so as to better foster integration among BbCN participants [8, 28, 29]. Integration of construction and BbCNs, however, is a complicated system manipulated by many elements [8, 28]. It underlines the necessity of an in-depth analysis by combining the characteristics of integration and the BbCNs [30].

*2.3. Theoretical Lens.* As recommended by Merschbrock et al. [15], a theoretical lens was applied to translate the findings into understandable messages. This theoretical lens assists researchers in developing explanations so that audiences are allowed to relate the findings to broader aspects and findings are made comparable to other cases. Selecting a theoretical lens enhances the internal validity of findings in the cases of studies through a pattern matching in which researchers compare patterns in established theories with empirically observed patterns [31].

Such systems, including BbCNs, are defined by socio-technical system (STS) theories as organizational work systems consisting of two subsystems, both socially and technically, that interact with and influence each other [32]. These subsystems integrate effectively with each other provided that the interdependency of the subsystems is clearly recognized [32, 33]. This premise is deemed valid for investigation integration in BbCNs [34] and has provided a theoretical basis for this study.

Sackey et al. [35] reviewed the existing theoretical models to select the most workable for analyzing BbCNs. They concluded that the Leavitt sociotechnical model [36], stereotype though, has evolved adequately and embodies key principles that vividly reflect the working nature in BbCNs. The model has been referred to for a long time in studying technology applications and shows validity in explaining the challenges modern STSs meet [37]. The Leavitt sociotechnical model is associated with technology, task, actor, and organization dimensions. The predictive power of the model, however, grows with the inclusion of new dimensions for specific BbCNs [35, 37]. In the context of innovation, Poirier et al. [38] added several dimensions as *process*, *context*, and *team* to increase the explanatory power of the model in dealing with modern teams. Sackey et al. [35] extended the model in construction by introducing several analytical concepts to produce a modified model that effectively reflects BIM-related systems.

*2.4. Integration Pentagon of BbCNs.* In this study, according to the Leavitt sociotechnical model by Leavitt [36] and the

extended framework proposed by Poirier et al. [38], an extended Leavitt sociotechnical model has been regarded as a so-called *integration pentagon* of BbCNs as shown in Figure 1.

As defined by prior researches, *context* dimension refers to the specific environment that all these dimensions are set within [38]. *Actor* dimension involves members of an organization who carry out the work. *Process* dimension refers to tools and inventions, and it also possesses a functional dimension [39, 40]. As highlighted in Figure 1, technology and process together compose the technology subset, while other dimensions belong to the social subset in a BbCNs [32]. *Organization* dimension refers to the common relational system of BbCNs, as shown in Figure 1. Structure and term dimensions have been synthesized into the *organization* dimension. *Task* dimension represents the characteristics of BbCNs activities tasks to be completed.

Thus, the system of integration in BbCNs comprises several actors, who use a range of tools and technologist to share their expertise and skills in a context of openness, trust, and mutual respect. They jointly work on the tasks that meet their common goal. The core premise embedded in this system is that all five dimensions are highly interrelated in a nondeterministic manner. These dimensions together lend a transformation of integration process and so on and ultimately catalyze the deeper integration in BbCNs [33]. The precondition has formed the pattern of *integration pentagon* that synthesizes five interrelated dimensions with reciprocal interactions. The *integration pentagon* shown in Figure 1 is adapted as the theoretical lens in this research, which provides a criterion to analyze where the gaps regarding integration in BbCNs are.

**2.5. Research Methods.** To reach the research objective, a “systematic mixed-methods review” has been used to identify the existing studies, research directions, and gap integrations in BbCNs. Systematic review is a tried and tested method, which is normally counted as superior in the matter of transparency. Compared with systematic ways for flagging up literature reviews, this method can easily be verified through replicating the research setting by other researchers. Aarseth et al. [41], however, pointed out that examining the bibliographic sources only by a review might be of bias, as it leads to subjective judgment and interpretation. Therefore, it is necessary to adopt a systematic mixed-method review in synthesizing literature to ensure breadth and depth in understanding [42]. The systematic mixed-method review synthesizes quantitative and qualitative research to collect and review the available literature on the topic of integration in BbCNs, integrating both the automatic and manual search strategies. To collect as many relevant published research papers, automatic and manual search strategies are turned to.

**2.6. Data Collection.** By providing a comprehensive and objective summary of the academic research achievements

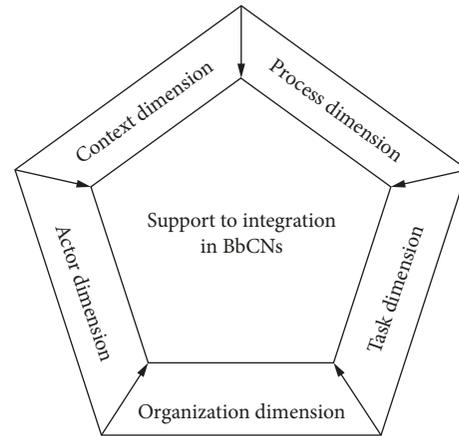


FIGURE 1: The principal knowledge domains (*integration pentagon*) of BbCNs: a theoretical lens in this study.

in the field of BIM and BIM-enabled projects over the past decade, we use the authoritative academic database *web of science* (WoS) as the main retrieval platform in this study. The database contains more than 12,000 journals worldwide, which was considered to be sufficient for a broad review on the integration in BbCNs.

**2.7. Bibliographic Analysis.** In the first stage, a bibliometric analysis method was adapted to review the available studies on BIM-mentioning integration. In this step, common word analysis and common citation analysis were made to explore the distribution and individual signs of literatures in a knowledge domain [43]. This enables researchers to analyze the intellectual landscape of a research area and fulfill their research objectives. There exists a wide range of computer programs for the bibliometric analysis, including VOSviewer, Cite-space, and Gephi. Results from previous researches have offered evidence possible to select computer programs for the bibliometric analysis, and the most important advantage of VOSviewer is that its outputs are closer to the data of WoS [44]. Therefore, VOSviewer has been applied for bibliometric analysis hereafter.

**2.8. Qualitative Analysis.** In qualitative analysis, what matters is to identify the findings various studies make and any respective gaps by comparing the notions, theories, and themes in a number of retrieved documents. The theoretical lens (*integration pentagon*) facilitates quantitative analysis in this study by serving as a classification code to classify the retrieved documents. The process of qualitative analysis follows the objective proposed by Gough [26] for qualitative phases in mixed.

### 3. Findings of the Study

**3.1. Bibliometric Analysis of the Literature on Integration in BIM.** To examine the attention level of integration in the field of BIM-related literature from a more comprehensive perspective, the first step in this study is retrieving the BIM-related studies from WoS. The selected results were all

academic papers published during the past decade (2008–2018), with title/abstract/keywords including the terms of “building information modeling,” “building information modeling,” and “building information modal.” The “BIM” was not set as the search keyword because papers of other disciplines that are not within the scope of this study might appear [45]. A total of 1019 BIM-related documents were retrieved as of February 2018. These papers were downloaded and used as core data to support the subsequent analysis in this study.

It has widely been accepted to use citation analysis as an important method to recognize the most influential literature in the field of BIM [46]. Therefore, the data of selected 1019 papers were uploaded to VOSviewer to establish a network of studies based on citations. As suggested by Riaz et al. [46], “fractional counting” served as a counting approach to minimize the influence of sources with plenty of citations on the network [10]. To ensure that the most influential literature can be identified in BIM, the least number of citations in one publication was set as 10. There were 35 papers meeting the threshold and thus were put in the network which is created based on connections and is shown in Figure 2.

Font size distinguishes the degree of citation concentration where larger size represents the higher level of citations concentration. The color of these nodes was set according to the level of the citation concentration, with red being the highest level. The literatures adjacent to the center of the network, as presented in Figure 2, are those with high level of citations, which are information sources and representative view of reference on BIM. An in-depth analysis on these works reveals that these BIM-related influential researches not necessarily focus on integration. Therefore, it can be deduced from Figure 2 that although integration is an important concept in BIM performance, it is not yet the mainstream research direction in BIM-related studies.

The second step in this study is retrieving the relevant studies with regard to integration within the corpus of BIM from the database set in the first step. The target publications were identified through the “searching within results” function of WoS. The function was served through setting integration as a target term in the keyword/abstract/title of the identified list of research papers on BIM (1019 researches). While retrieving, we filtered the results by using the following combinations of terms: “collaboration” OR “interoperability” OR “integrated” OR “coalitions” OR “interaction” OR “coordination” OR “process integration” OR “technology integration” OR “system integration” OR “partner integration” OR “customer integration” OR “supplier integration” OR “manufacturing integration” OR “information integration” OR “interoperability”. Accordingly, the number of documents retrieved dropped from 1019 to 90 (ended in February 2018). All of these 90 BIM-related papers regard the integration on their keyword/abstract/title in varying degrees.

A clear display of the main outlets for publishing researches might contribute to offer a more comprehensive perspective to capture the present research state of integration in BbCNs. The VOSviewer was thus utilized to

extract and establishes a source network of main outlets from the dataset which was formed by the second step. In the course of operation, the “analysis type,” “analysis unit,” and “count method” were set to “citations,” “sources,” and “fractional counting,” respectively. In the network, 79 sources in total were defined. With the least number of documents and citations for each source was set at 2 and 1, respectively, with 38 sources meeting these criteria contained in the source network of main outlets. The network also presents the information flow between nodes, which indicates the citation strength of the data. The tightness of links and the size of nodes suggest the relative impact of the node and the intensity of their respective connections [46].

According to the network shown in Figure 3, the most frequently cited journal in this collection is “*Automation in Construction*,” which was identified as the most effective channel on this topic. From the arrow directions in this network, the information flow begins with “Automation in Construction” as a source of citations. The published papers in this journal generally are based on the researches focusing on technology, software, integrated technologies, and automation. This reveals the fact that the effective outlets hitherto are highly technology oriented, while journals focusing on professional issues, management, construction, and education are less influential in terms of the integration in BIM. Just as contended that the BIM study is almost entirely driven from the perspective of technology.

As a result, available researches, technology oriented on researches into BIM, have not addressed project management and managerial features of integration. These findings point out that enhancing integration in BbCNs is still considered as a technical matter, despite that researchers increasingly value the key role of managerial components in BbCNs.

To comprehend the contents mentioned in researches connected with integration in BbCNs, the cooccurrence network of keywords was established from the dataset containing 90 documents. “Authors keywords” rather than all keywords were applied to create visualization. The method of “fractional counting” allowed us to extract 454 keywords from the dataset. The least occurrence number of keywords is set at 5, and it resulted in a cooccurrence network of 51 terms with 178 links. As Lee and Yu [20] said, the author keywords present the core of the research, and the key point of the survey was selected by authors carefully. Therefore, the cooccurrence network of keywords shown in Figure 4 demonstrates the highlights of research covered by the literature included in the dataset.

The idea of the PageRank algorithm originates from the mechanism of citation indexing. The more the papers are cited by the more authoritative papers, the more valuable these papers are. This algorithm allows us to rank the nodes based on their importance in the network. From the distance between the nodes and the strength of those links (Figure 4), it is seen that everything highlighted here is BIM or expansions of BIM, while integration was found to be associated only with the node of *benchmark, construction, and information technologies*. The size of the node also represents the degree of recognition, and the results drawn





TABLE 1: Study associated with integration in BbCNs and the dimensions targeted in each study.

ID	Study associated with integration in BbCNs	Dimensions of integration pentagon
1	Akintola et al. [47]	Actor
2	Demirkesen and Ozorhon [12]	Actor/context
3	Habibi [48]	Actor
4	Jacobsson and Linderoth [49]	Actor/context
5	Linderoth [13]	Actor
6	Ozorhon et al. [50]	Actor
7	Rahman et al. [51]	Actor
8	Shao [52]	Actor
9	Poirier et al. [53]	Context
10	Liu et al. [5]	Context/process
11	Fadeyi [54]	Context
12	Abbas et al. [55]	Context
13	Grilo and Jardim-Goncalves [27]	Context/process
14	Babič et al. [56]	Context
15	Gemünden et al. [57]	Organization
16	Eskerod and Larsen [58]	Organization
17	Wen and Qiang [59]	Organization/task
18	Oti et al. [60]	Organization
19	Mignone et al. [61]	Organization
20	Al Mousli and El-Sayegh [17]	Organization
21	Son et al. [62]	Organization
22	Berteaux and Javernick-Will [30]	Organization
23	Whyte and Hartmann [63]	Organization
24	Ajam et al. [64]	Organization/process
25	Solihin et al. [23]	Process
26	Dave et al. [65]	Process
27	Ahola et al. [11]	Process
28	Ilhan and Yaman [66]	Process
29	Forgues et al. [67]	Process
30	Amann and Borrmann [45]	Process
31	Tarandi [68]	Process
32	Arayici et al. [69]	Process
33	Zhang et al. [70]	Process
33	Wang et al. [29]	Process
34	Ding et al. [71]	Process
35	Yi et al. [6]	Process
36	London and Singh [72]	Process
37	Chen et al. [18]	Process/task
38	Sanguinetti et al. [73]	Process
39	Singh et al. [74]	Process
40	Gassel et al. [19]	Task
41	Papadonikolaki et al. [2]	Task
42	Shin [75]	Task

*3.4. Actor Dimension of Integration in BbCNs.* Implementation of a new technology inevitably leads to the emergence of new work roles of the individual team members [39]. As Azhar [78] said, BIM represents a new paradigm within AEC, one that encourages integration of the roles of all stakeholders on a project. As illustrated in Table 1, 8 studies (20%) focus on the roles of BbCN actor. These studies in this category show that the present organizational actors were not supportive of the concomitant process changes associated with new technological solutions [79] because in effect, the changes intrinsic to BIM implementation is substantial and it necessitates new set of skills and new ways of thinking.

Consequently, the roles of BbCNs, which are relevant for supporting BbCNs-enabled project, have been identified: include not only technical competencies but also skills related to process changes and management [47, 48, 51]. Concerning expectations of the characteristics of a BbCNs actor, these researches had relatively similar opinions that are made in these researches. Besides, there seems a high expectation on the characteristics of a BbCNs actor, especially in terms of excellent interpersonal skills, commitment, and leadership in the study of Jacobsson and Linderoth [49] and Linderoth [13]. Bosch-Sijtsema et al. [80] and Shao [52] compared the similarities and significant differences between BIM and non-BIM actors in characteristics, experiences, and education and found that BIM actors considered their roles, characteristics, and education as coordinating and pushing for change.

In conclusion, we find that the data from these studies provide insights into the level of professional competence of the BbCNs actor. Nevertheless, there has been scant research on the responsibilities and obligations of BbCN-related roles. Given present incomplete researches, one might conclude that a systematic study on the topic of the BbCNs actor is of necessity.

*3.5. Process Dimension of Integration in BbCNs.* As shown in Table 1, 18 studies explore the importance of process on integration in BbCNs. This subsystem involves business processes and the technologies (tools, techniques, machines, etc.) with functionalities to perform required processes and enhance the overall performance of the system [71, 72, 74]. Studies falling in this category such as Uhm et al. [81], Liu et al. [5], Takim et al. [82], and Succar [83] underline the use of software and tools as required processes to support integration in BbCNs.

Solihin et al. [23] proposed a framework that can more fully integrate different models into an integrated model in a federated environment. Liu et al. [5] stated that the reliable network-based systems are conducive to achieving successful integration. Amann and Borrmann [45], Ajam et al. [64], Sanguinetti et al. [73], and Yi et al. [6] identified that cloud-based platforms are of a great potential for integrating models, simulating components, and providing seamless data sharing for end users in BbCNs. Ahola et al. [11] and Arayici et al. [69] proposed an interoperability specification development approach for intergraded BIM use in performance-based design. Zhang et al. [70], Dave et al. [65], and Ilhan and Yaman [66] also proposed a multiserver information sharing with a private cloud after analyzing the requirements for cross-party integration in a BIM scenario.

Scholars, however, came upon different points of view. Just as what has been described by Grilo et al. [84], process integration cannot be simply regarded as a result of cloud-based tools and coordination and collaboration among stakeholders are equally important. In terms of this arguments, we propose that the follow-up researches into process integration should focus on both technology and management perspectives.

**3.6. Organization Dimension of Integration in BbCNs.** Following the presentation in Table 1, 10 studies stress the importance of organization on integration in BbCNs. Organizational dimension is to integrate a set of participants with different functions into an organic organization. Arayici et al. [69] stated that the problem of interoperability between organizations exists in many areas where collaboration, interaction, and data exchange are required. This is especially suitable for the construction, engineering and construction (AEC) fields, where the evolution of practice and the BIM paradigm have reinforced the need for integration among different stakeholders.

Whyte and Hartmann [63], Gemünden et al. [57], and Oti et al. [60] found that BIM become a “cultural driver” for integration, and each partner in the BIM-enabled project will bring new aspects to the project organization, which will require organization changes in how BIM is applied and used. The findings present in the literature work in this category suggest that the redefining work roles [9, 85] and designing relationships [30] have been considered as positive factors to support organizational integration. In addition, some scholars have proposed that establishing the mechanism of benefit conforming and contradiction handling contribute to can effectively improve the level of trust and then promote the cooperation of participants [17, 59, 61].

Building on the discussions above, the future research on organization dimension is expected: (1) investigate the contract forms of BbCNs, (2) identify the supportive organizational structures, and (3) follow a multisystem thinking of a governance model.

**3.7. Task Dimension of Integration in BbCNs.** As inferred from Table 1, 5 studies explore integration from micro-perspective, focusing on the importance of tasks on integration in BbCNs. In these studies, discussions are made on the potential impact of tasks performed by a BbCNs and how they influence team functioning and effectiveness [75, 81]. An interesting result is that seemingly low volume of papers addresses the *actor* aspect of BbCNs, this being referred to as one of the best aspects of BbCNs, though.

Literatures in this category attach important specific tasks and activities of integration in BbCNs, such as integrated knowledge, integrated changes, and integrated production factors. As illustrated by Chen et al. [18], Xue et al. [77], and Wen and Qiang [59], integrated knowledge is definitely essential for fulfilling integration in BbCNs. This is because knowledge disclosure would result in repetitive work and waste, lack of innovation and thus leads to organization inefficiency. The studies by Gassel et al. [19] proved that the integration of changes leads to fewer obstacle for information transmission and less time for information interaction between participants, thus making the change more time sensitive. The findings also indicate that BbCNs could not only support the project development process as a systematic management tool but also serve as a core data generator and platform allowing other participants to perform further tasks.

Generally, previous researchers into task dimension highlight the tasks required to implement BbCNs, yet with insufficient details, i.e., there shows a lack of more detailed research. Such as a lack of research on how task types and task complexity influence the performance of BbCNs implementation.

## 4. Implications of the Findings

Identifying further strategies for BbCNs is an intriguing area for future research. Based on the scientmetric analysis, some fundamental viewpoints and frontier insights with respect to the existing literatures into integration in BbCNs have been developed. Systematic mixed-methods allow us to review the available literatures on BIM, and the result suggests that integration is a core element in the BIM literature. Although the potential value of integration in advancing successful BIM-based projects have been accepted [9], the research into integration in BbCNs has not received enough attention it deserves (Figure 2). The findings also show that previous studies mainly explored integration in BbCNs from a technology-oriented orientation (Figure 3). Although BIM is a sociotechnical system [5], the research into BIM has not been carried out from the managerial perspective, and deficient focus has been made on social-related features of integration within BbCNs [9]. Such a research situation runs counter to the widely held view in the industrial sector that “successful integration originates from 80% of people and 20% of the technology or information.” It shows that the future research into integration in BbCNs must shift the focus to the managerial areas.

To reach the study objective, a qualitative analysis based on *integration pentagon* is conducted to exam and demonstrate the current status and future directions of integration in BbCNs. The findings call for future research to target these dimensions such as context, tasks, actors, and organization, which are currently under-represented in studies exploring integration in BbCNs. The findings magnified the gap in the study of *context* dimension so that future research is expected to cultivate the incentive mechanism for promoting the enthusiasm of participants to implement BbCNs in project management practice. The research gaps related to the *actor* dimension call for a systematic research to identify the responsibilities and obligations of BbCNs-related roles. As for the *organization* dimension, three components including the contract forms of BbCNs, a multisystem thinking of the governance model, and the supportive organizational structures should receive attention. The challenge the existing studies of *task* dimension confronts is that implementing BbCNs often requires a specific environment, so the future research in this regard must be highly bespoke and context specific. In other words, future research on task dimension should take into account its interrelationships with organizational context, structures, roles, and other elements.

In addition, the outcome of this study also reveals that existing BIM researches explore integration from a fragmented and disjointed way. Namely, isolated antecedents are observed in various researches with little paying no attention

to the importance of associations and the synergy between these antecedents. These antecedents' dimensions of integration in BbCNs have rarely been considered as necessary components of a unified system. There is a lack of necessary attention to reflect how the integration is affected by misalignment between these dimensions. Even if Leavitt had earlier argued for the interrelatedness of these sociotechnical system dimensions and for the need for a comprehensive consideration. These conclusions consequently lead to a call for more studies that examine the interacting impacts and synergy among the interrelated integration dimensions in BbCNs.

## 5. Conclusions and Future Research

Although enhancing integration in BbCNs has been a well-recognized problem, this study explores the problem in an all-round way. This study has drawn findings from a batch of literature works comprising 42 studies. A systematic mixed-method review was used to analyze the storyline of research studies relevant to integration in BbCNs. The results provide a solid foundation for the research of integration in BbCNs. Moreover, this study also extends the scope of research into integration in BbCNs by focusing on the significance of social components. The primary theoretical and methodological contribution made by this study to the body of knowledge of integration in BbCNs can be summed up in three aspects.

First, this study maps a research area of integration in BbCNs based on the knowledge base, domains, and evolution by using a systematic mixed-method review. The study results highlight how the research of integration of BbCNs evolves, thus greatly contributing to understanding the status quo of BIM knowledge. The methods presented detailed in this study can be generalized and used as an effective tool for mapping discipline knowledge. It is recommended that future studies should be conducted periodically to improve the BOK of BbCNs provided in this study.

Second, in this study, an extended Leavitt sociological model was used for reference to build an *integration pentagon* which was made up of context, process, organization, task and actor. The *integration pentagon* is used as the conceptualization theoretical lens offering researchers to identify the existing gaps in the literature regarding the integration in BbCNs and providing a theoretical foundation to test and guide future research. The *integration pentagon* also enhances our comprehension of the integration antecedents for BbCNs by emphasizing the essentiality of pondering these enablers from an all in view.

More importantly, these findings provide a valuable reference to the developers of BbCNs to understand the major barriers in their decision-making and to government aiming at promoting BIM or BbCNs in the construction industry with relevant policies and incentives.

Despite that the contributions of this study have been mentioned, some of the study limitations must be acknowledged before applying the findings. First, the research is made merely based on WoS publications. Another

limitation involves generalization, which is a result of using specific keywords which may omit the relevant research. In addition, the *integration pentagon*, which has been used to match and encode studies on integration, could be considered subjective in nature. In future studies, this may occur by incorporating members to check validation processes to enhance the credibility. In addition, a lack of publications in available databases also affected the results of bibliometric analysis.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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