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VIEWPOINT

Where the Gaps Lie: Ten Years of Research into Collaboration on BIM-Enabled Construction Projects

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Abstract

A BIM-enabled Construction Project (BIMCP) refers to a project involving relevant BIM tools to generate, exchange and manage project data between project participants. Success in delivering BIMCPs largely relies on how effective project members collaborate. As a result, collaboration on BIMCP has become a growing field of research while a review of studies on collaboration on BIMCPs is still missing. To address this gap, this paper presents the findings of a systematic review on studies devoted to collaboration on BIMCPs over the past 10 years (2006-2016). To this end, 208 studies published in 12 ICT-oriented journals in the construction context are thoroughly reviewed. The findings bring to light that studies on collaboration on BIMCPs are sporadic, isolated and focus on narrowed, limited and disjointed areas associated with collaboration. The study contributes to the field through highlighting the gaps of the existing literature on the topic. This provides a stepping stone to direct future inquiries that target collaboration on BIMCPs.

Keywords

Building information modelling, collaboration, construction projects, systematic review

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Introduction

The advent of Building Information Modelling (BIM) has led to significant changes in the way construction projects are delivered in terms of the style of information sharing among the parties involved (Liu, van Nederveen and Hertogh, 2016). BIM-enabled Construction Projects (BIMCPs) are delivered by a network comprising members from specialist organisations that are contracted to perform BIM-related works (Grilo et al., 2013). These members are expected to work together collaboratively where the challenges of managing multiple disciplines and organisations involved in BIMCPs have proven problematic (Alreshidi, Mourshed and Rezgui, 2016; Liu, van Nederveen and Hertogh, 2016). Lack of collaboration among members of BIMCPs is still one of the major impediments to successful delivery of BIM-enabled projects (Hosseini et al., 2016; Volk, Stengel and Schultmann, 2014). As a result, the report by McGraw-Hill (2012, p.7) recommended focusing on fostering collaboration on BIMCP as "the most important area of BIM investment". This has resulted in an upsurge in the number of studies on this area (Mignone et al., 2016).

Having a large body of literature on a topic necessitates conducting regular critical review studies to uncover certain research requirements, which have not been adequately met in the current research trend (Lu et al., 2015). This study intends to address this need through mapping the status quo of the body of literature allocated to collaboration on BIMCPs. To this end, the study aims at presenting a picture of the findings of available studies devoted to collaboration on BIMCPs to unearth the gaps and trends.

Collaboration on BIM-enabled Construction Projects

Hughes, Williams and Ren (2012) state that collaboration in construction studies is usually seen as an umbrella term that refers to partnering, alliancing, networking and joint ventures, thus perceived in different ways by different stakeholders of projects. As put by Van Gassel, Láscaris-Comneno and Maas (2014, p.85) and Azhar, Khalfan and Maqsood (2012), collaboration is "a creative process undertaken by two or more interested individuals, sharing their collective skills and knowledge in an atmosphere of openness, honesty, trust, and mutual respect, to jointly deliver the best solution that meets their common goal". The technical capabilities of BIM in facilitating a collaborative environment has been promoted as a selling point for BIM methodology (Alreshidi, Mourshed and Rezgui, 2016; Liu, van Nederveen and Hertogh, 2016). Gaining the full benefits offered by BIM methodology is contingent upon effective collaboration and coordination of activities in BIMCPs (Alreshidi, Mourshed and Rezgui, 2016; Bassanino, Fernando and Wu, 2014; Volk, Stengel and Schultmann, 2014). In essence, implementing BIM in an environment where effective collaboration is absent is "scratching the surface" (Mignone et al., 2016). To address this, investigators have identified a wide range of problems that hinder establishing a collaborative environment in BIMCPs (Bassanino, Fernando and Wu, 2014; Mignone et al., 2016). Of these, Olatunji (2011b) contended that the conventional legal structure on construction projects is a barrier to collaborative attempts in BIMCPs. From another vantage point, Merschbrock (2012) attempted to foster collaboration using enhanced collaboration technologies. Sackey, Tuuli and Dainty (2015) asserted that members of BIMCPs are to become constant learners in order to foster collaboration. MacDonald and Mills (2013) proposed an integrated approach for teaching BIM subjects at universities to address the lack of collaboration in BIMCPs through training potential graduates that come to the construction industry. As another suggestion, Merschbrock and Munkvold (2014) maintained that enhancing collaboration in BIMCPs

may not occur in the absence of instructive protocols, manuals and guidelines. From a broader viewpoint, Liu, van Nederveen and Hertogh (2016), Homayouni, Neff and Dossick (2010) and Shelbourn et al. (2007) emphasised the crucial impacts of three dimensions of technology, people and process on collaborative nature of BIMCPs.

Despite the individual contributions of these studies on the topic, the adequacy and comprehensiveness of such attempts are to be assessed against an established theory or framework as described below.

Collaborative Working Model (CWM)

Patel, Pettitt and Wilson (2012) developed a Collaborative Working Model (CWM) to distinguish the main factors that act as the antecedents of collaboration. The proposed CWM identified 6 primary factors to be central to establishing a collaborative environment in any team. These were termed as "context", "support", "tasks", "interaction processes", "teams" and "individuals". "Context" defines the types of individuals and teams involved. As for "support", the difference between a successful collaboration effort and an unsuccessful one is directly affected by the level of management support in terms of providing resources and tools. "Tasks" represent the characteristics of the responsibilities and activities to be completed by the team at hand. "Interaction processes" encapsulate the behaviours that follow each other in a collaborative effort to convert resources into a product or service. "Teams" as another antecedent of collaboration represents all the elements relevant to the structure of teams being co-located, virtual and the configuration of members in terms of the distance and time. The factor labelled as "individual" refers to the performance of team members in terms of social and interaction activities. CWM is particularly applicable to virtual construction/ engineering teams as asserted by Patel, Pettitt and Wilson (2012). Thereby, CWM was selected as the yardstick to evaluate the adequacy of scholarship on collaboration on BIMCPs in the present study.

Research method

The primary method deployed in this study entailed a systematic review of literature on collaboration in BIMCPs. Systematic reviews are invaluable scientific activities through which a large amount of information produced by scholarship are reduced to "palatable pieces of information for digestion" (Mulrow, 1994, p.597). Systematic reviews are needed in any field of study. That is, systematic reviews enable researchers to assess the consistency and adequacy of scientific attempts and uncover the gaps within the existing literature on a topic (Mulrow, 1994). The procedure for conducting the systematic review in the present study was informed by the procedure proposed by Lu et al. (2015) for conducting systematic reviews within the construction context according to a two-staged procedure as illustrated in Figure 1.

To balance the quality of the review vis-à-vis the number of literature relevant to collaboration on BIMCPs, the ICT-oriented journals in the construction context were considered. That was because, BIM and collaboration on BIMCPs are subsets of Information and Communication Technology (ICT) as asserted by Hosseini et al. (2015). As such, outlets devoted to ICT in the construction context were deemed the most suitable sources to provide a comprehensive coverage of studies conducted on collaboration on BIMCPs. Such journals were identified through using the list of ICT-oriented journals in construction research as suggested by Lu et al. (2015). This list comprised a total of 12 journals as illustrated in Table 1, which

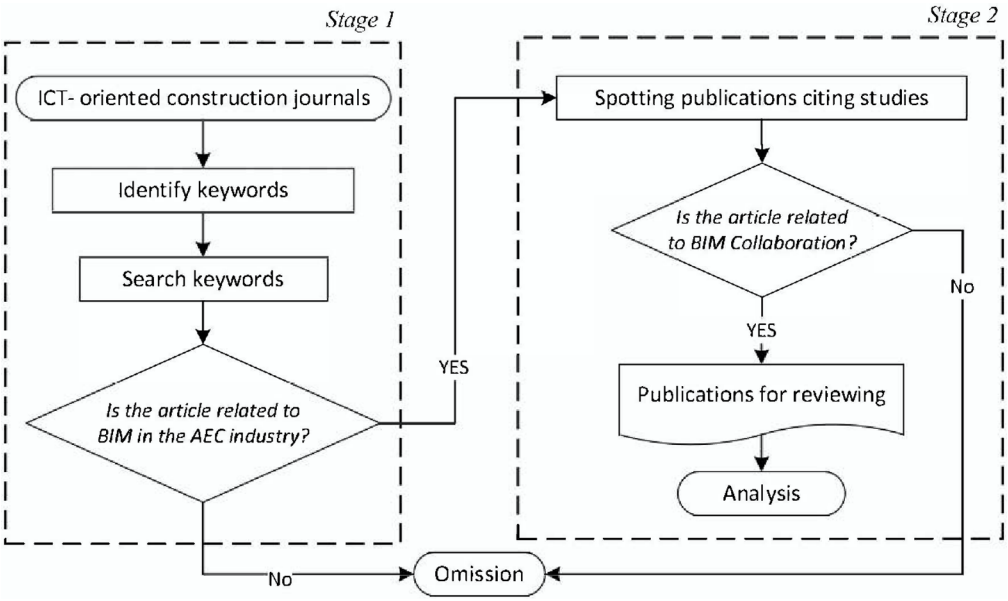


Figure 1 Procedure of systematic review

Table 1 ICT- oriented journals in the construction context (input from Lu et al. (2015))

	Journal	Abbreviation
1	Automation in Construction	AUTCON
2	Journal of Information Technology in Construction	ITCON
3	Journal of Computing in Civil Engineering	JCCE
4	Construction Innovation: Information, Process, Management	CI
5	Architectural Engineering and Design Management	AEDM
6	Advanced Engineering Informatics	AEI
7	Journal of Construction Engineering and Management	JCEM
8	Journal of Management in Engineering	JME
9	Construction Management and Economics	CME
10	International Journal of Project Management	IJPM
11	Computer-Aided Civil and Infrastructure Engineering	CACIE
12	Project Management Journal	PMJ

provided the sources for spotting publications. As such, this review targeted journal articles published in the last 10 years (from 2006 to 2016). The list of journals covered first-tier outlets for scholarly publications in the construction field alongside several journals specifically devoted to the ICT domain. This was justified as, suggested by Okoli and Schabram (2010), investigators are expected to find and exhaust all available sources when conducting systematic reviews on ICT-related topics.

The Keywords of BIM (Building Information Modelling), collaboration, integration and IPD (integrated project delivery) were set to be screened primarily while "collaborative" and "integrated" terms were also considered for identifying relevant published studies. The reason for inclusion of these keywords was based on the common trend towards widespread use of BIM as the principal means to deliver projects in IPD mode and direct associations of these concepts with collaboration as argued by Ma and Ma (2017).

Findings of the study

The keywords as discussed were utilised successively. That is, initially the keyword BIM was utilised to search publications within the journals as illustrated in Table 1, thus a total of 1034 BIM-related papers were found. To narrow down the search, the keywords 'collaboration' or 'integration' or 'IPD' or 'collaborative' or 'integrated' were utilised to identify applicable studies to the topic among the 1034 publications. Titles, abstracts and keyword sections of these 1034 articles were screened. Thus, a list of 208 papers relevant to BIM and devoted to the concept of collaboration was detected. As the final stage of selecting articles, and to specify the most relevant papers, at least two members of the research team examined all 208 articles to identify the papers with a focus on collaboration in BIMCPs. Finally, 62 papers (see Table 2) were identified as directly relevant studies to be thoroughly analysed as discussed below.

PRIMARY OUTLETS

As illustrated in Table 2, among the ICT-oriented journals in the construction industry, AUTCON and ITCON have been the most popular outlets for publishing studies on collaboration on BIMCPs. AUTCON and ITCON (see Table 2) have published the largest number of studies on the topic with 19 articles (31%) and 14 articles (23%), respectively. On the other hand, project management related journals have the smallest share. This reveals a common trend dominant within the current literature. That is, technology-oriented journals are the desired destination for studies on collaboration on BIMCPs while the outlets focused on construction, project and management aspects have been overlooked. This could be translated to the corresponding aims and objectives of the published studies on these journals. In a wider context, it can be stated that team working, construction context and the project nature of collaboration on BIMCPs are being overshadowed by technology within the published studies.

TREND OVERVIEW

The number of articles published on collaboration on BIMCPs is illustrated in Figure 2. As BIM is a new methodology to the construction industry, the number of publications before 2007 was significantly low (see Figure 2). Nevertheless, from 2007 onwards the rate has enjoyed an overall continuous growth. The trend line as illustrated in Figure 2 attests to an increasingly noticeable attention to the concept of collaboration on BIMCPs among the scholarship investigating BIM. Judging from the shape of the trend line, the number of publications is expected to increase steadily in the upcoming years.

COUNTRY/REGION

As for the country and region contribution, Figure 3 illustrates the total of 62 publications based on their region and country of origin. The context of the study referring to the country

Table 2 Outcomes of the relevant published articles in ICT-oriented journals in the AEC industry

Journal	Search outcomes through keywords						Associate to BIM & Collaboration	Examination Outcomes	
	BIM articles	BIM & Collaboration	BIM & Collaborative	BIM & Integration	BIM & Integrated	BIM & IPD		Collaboration in BIM	Percentage
AUTCON	372	17	8	28	65	1	69	19	31%
ITCON	73	16	15	12	15	1	30	14	23%
AEDM	42	12	15	20	20	2	21	9	15%
JCEM	116	7	0	14	14	1	14	5	8%
CI	52	9	2	9	10	1	17	4	6%
CME	81	18	11	19	13	2	18	4	6%
IJPM	19	1	1	1	1	0	3	2	3%
JCCE	117	3	1	12	12	0	19	2	3%
AEI	101	1	2	6	10	0	10	2	3%
JME	41	1	1	4	4	0	6	1	2%
CACIE	14	1	0	0	0	0	1	0	0%
PMJ	10	0	0	0	0	0	0	0	0%
Total	**1038**						**208**	**62**	**100%**

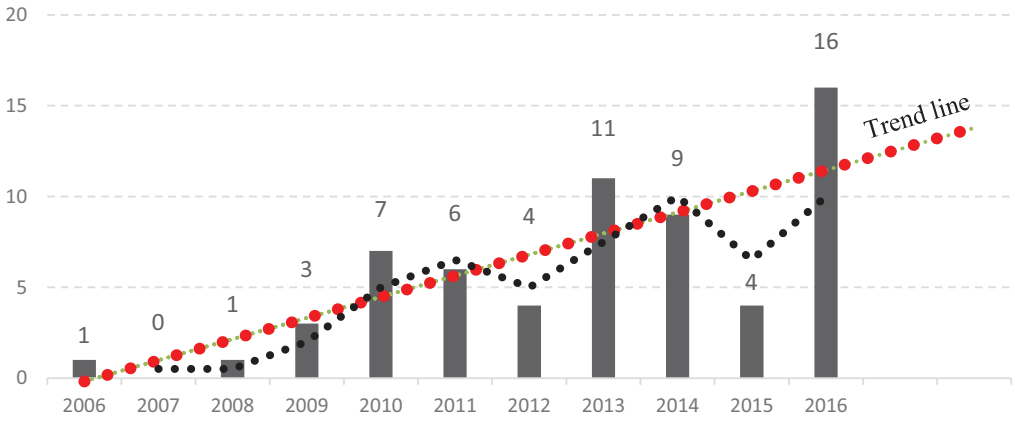


Figure 2 Trend overview of the publications on collaboration on BIMCPs



Figure 3 Worldwide distribution map of the 62 reviewed articles

or region where data were collected or location of the studied case were considered to specify the country or region associated with a study. As indicated in Figure 3, the UK, followed by the North America, have been the sources of the largest number of studies with 35% and 21% respectively, of the total world publications allocated to collaboration on BIMCP. This shows the concentration of research on the topic (above 56%) within these two regions whereas the rest of the world are noticeably behind.

Benchmarking against the Collaborative Working Model (CWM)

Each identified paper was critically reviewed and the contents were analysed in terms of associating the collaboration factors targeted in each paper with the antecedents of collaboration as outlined by CWM as discussed. To this end, the contents of identified studies were assigned to the factors as described by CWM. This was through an in-depth analysis of the content by at least two members of the research team, which resulted in defining the main factors covered by each of these 62 studies as illustrated in Table 3.

Table 3 Factors covered by studies on collaboration on BIMCPs using the CWM

#	Study	Collaboration factors (CWM)					
		Context	Technology	Tasks	Interaction processes	Teams	Individual
1	(Abrishami et al., 2014)		•	•			
2	(Abuelmaatti and Ahmed, 2014)	•	•	•			
3	(Adamu, Emmitt and Soetanto, 2015)		•	•	•		•
4	(Ahuja et al., 2016)	•	•		•		
5	(Ajam, Alshawi and Mezher, 2010)	•	•			•	
6	(Al Mousli and El-Sayegh, 2016)	•	•		•		
7	(Amann and Borrmann, 2016)		•				
8	(Babič, Podbreznik and Rebolj, 2010)		•				
9	(Bassanino, Fernando and Wu, 2014)		•	•	•	•	
10	(Becerik-Gerber, Gerber and Ku, 2011)		•				•
11	(Boton, Kubicki and Halin, 2013)		•	•			
12	(Chen and Hou, 2014)		•		•	•	
13	(Chen et al., 2013)	•					
14	(Ciribini, Mastrolembo Ventura and Paneroni, 2016)		•		•		

Table 3 continued on the next page

Table 3 (*Continued*)

#	Study	Collaboration factors (CWM)					
		Context	Technology	Tasks	Interaction processes	Teams	Individual
15	(Dossick and Neff, 2009)	•	•		•	•	
16	(Fernando, Wu and Bassanino, 2013)		•		•	•	
17	(Franz et al., 2017)	•	•		•		
18	(Fu et al., 2006)		•				
19	(Goulding, Pour Rahimian Leilabadi and Wang, 2014)		•		•		
20	(Grilo and Jardim-Goncalves, 2013)	•	•				
21	(Gu and London, 2010)		•		•	•	
22	(Hammad et al., 2016)	•					•
23	(Hassan Ibrahim, 2013)		•		•		
24	(Hu and Zhang, 2011)	•	•				
25	(Hu et al., 2016)		•		•		
27	(Isikdag, 2012)	•	•		•	•	
26	(Isikdag and Underwood, 2010)		•		•		
28	(Jason and Umit, 2011)		•				

Table 3 continued on the next page

Table 3 (*Continued*)

#	Study	Collaboration factors (CWM)					
		Context	Technology	Tasks	Interaction processes	Teams	Individual
29	(Jiao et al., 2013)		•		•	•	
30	(Kent and Becerik-Gerber, 2010)		•	•	•	•	
31	(Kihong Ku and Mahabaleshwarkar, 2011)	•	•		•		•
32	(Kokkonen and Alin, 2016)	•		•			
33	(Ku and Pollalis, 2009)	•	•		•	•	
34	(Ku K et al., 2008)	•	•		•		
35	(Lee, Eastman and Lee, 2015)	•	•		•	•	
36	(Liu, Al-Hussein and Lu, 2015)	•	•				
37	(Liu, van Nederveen and Hertogh, 2016)		•		•		•
38	(London and Singh, 2012)	•	•		•		
39	(Merschbrock, 2012)	•	•		•		
40	(Mignone et al., 2016)			•		•	•
41	(Niknam and Karshenas, 2015)		•	•			
42	(Ochieng and Price, 2010)	•	•		•		
43	(Olatunji, 2011a)	•	•	•		•	

Table 3 continued on the next page

Table 3 (*Continued*)

#	Study	Collaboration factors (CWM)					
		Context	Technology	Tasks	Interaction processes	Teams	Individual
44	(Owen et al., 2010)	•	•		•		•
45	(Pala et al., 2016)		•		•		
46	(Papadonikolaki, Vrijhoef and Wamelink, 2016)		•		•	•	
47	(Park and Kim, 2013)		•				•
48	(Pikas, Sacks and Hazzan, 2013)	•	•				•
49	(Poirier, Forgues and Staub-French, 2016)	•					
50	(Rafiq and Rustell, 2013)		•		•		
51	(Robson, Boyd and Thurairajah, 2016)	•	•		•		
52	(Sackey, Tuuli and Dainty, 2015)	•	•		•		
53	(Shafiq, Matthews and Lockley, 2013)		•		•	•	
54	(Sidawi and Hamza, 2012)	•	•		•		
55	(Singh, Gu and Wang, 2011)	•	•		•		
56	(Solnosky, Parfitt and Holland, 2014)	•	•				•
57	(Succar, 2009)		•	•	•	•	
58	(Van Gassel, Láscaris-Comneno and Maas, 2014)	•	•		•		•

Table 3 continued on the next page

Table 3 (*Continued*)

#	Study	Collaboration factors (CWM)					
		Context	Technology	Tasks	Interaction processes	Teams	Individual
59	(Walker, 2016)		•				•
60	(Wallace Imoudu, Uche Godwin and Kherun Nita, 2014)		•		•		
61	(Wei et al., 2014)		•		•	•	•
62	(Zanni, Soetanto and Ruikar, 2016)		•		•	•	
Share of each factor		**48%**	**92%**	**18%**	**63%**	**29%**	**21%**

As illustrated in Table 3, studies on collaboration on BIMCPs for the most part (92% of studies) have targeted the technology factor. Likewise, studies have had a bias towards interaction processes (63%) and context (48%). The findings show that collaboration factors such as individuals, tasks, and teams (see the definitions by CWM) have been often overlooked with only a handful of available studies referring to them in investigating collaboration on BIMCPs. This points to a concentration of the current body of literature on certain factors of the CWM framework while several factors are being overlooked as discussed next.

Discussion of the findings

The status of publications and the comparison of the objectives of available studies both attest to the concentration on "technology" as one antecedent of collaboration outlined by CWM and dominance of technology-oriented studies within the area of collaboration on BIMCP. This resonates with anecdotal statements by Homayouni, Neff and Dossick (2010); Mignone et al. (2016); Shelbourn et al. (2007) who referred to such a gap in the body of knowledge on collaboration on BIMCP. This could be inferred that the present study provides evidence to corroborate the intuitive awareness of such a gap as pointed out in previous studies.

Furthermore, the study reveals the disjointed and fragmented nature of scholarship on the topic. Such one-sided approach to collaboration on BIMCPs, according to the findings of the study, is visualised in Figure 4. As illustrated in Figure 4, almost all factors described by the CWM (Patel, Pettitt and Wilson, 2012) are in need of further inquiries as fertile grounds for future research on collaboration on BIMCPs. Of particular interest are areas associated with "individuals", "tasks" and "teams" for which the number of studies has been hitherto very limited. This points to a necessary shift in defining the objectives of future studies on collaboration on BIMCPs by diversifying the defined objectives and switching the primary goals from "technology" towards other factors outlined by CWM. The framework deployed here namely CWM and the visualisation of the gap (see Figure 4) could be treated as benchmarks for directing future studies towards the key areas in need of special attention.

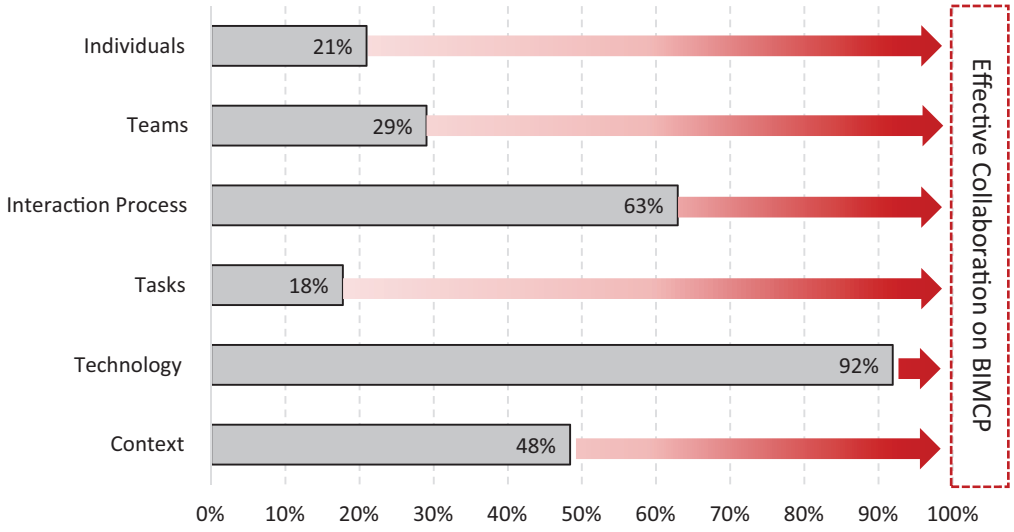


Figure 4 Gap visualization of the body of the knowledge on collaboration on BIMCPs according to CWM

Conclusion

This study contributes to the body of the knowledge on BIM and in particular, collaboration on BIMCPs in several ways. First, the study identifies and provides a shortcut to the existing literature targeting collaboration on BIMCPs for investigators interested on this topic. Second, the study draws a picture of the current state of research on collaboration on BIMCPs. This includes identification of predominant research trends, preferences, and potential concentration areas as well as neglected and overlooked areas when it comes to the factors affecting collaboration on BIMCPs. Furthermore, the study provides evidence for anecdotal statements in previous studies regarding the gaps within the body of the knowledge on the topic. On top of that, an established benchmarking tool as CWM that was utilised on this study and the visualisation of gaps provides a sound basis for future investigators in identifying and spotting areas that need further research. The clear message is that the time has come for investigators to move beyond the technology-oriented debate in collaboration on BIMCPs and paying undivided attention to all the factors outlined through the CWM. It is now incumbent upon the researchers to move the prevalence of their research studies from technology to cover all the factors outlined by CWM. Focusing on theories outlining the interactions among human beings in technology-oriented networks would provide a solid basis for future inquiries on the topic. Such attempts need established theories to be imported to the construction context through following a multidisciplinary approach.

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