BIM as a Boundary Object in Construction Projects: A Knowledge-as-Practice Perspective

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To Study BIM as Boundary Objects from the Knowledge-As-Practice Perspective in the Construction Project – A Conceptual Framework

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Abstract. Collaboration in a construction project faces challenges of knowledge sharing among different team members across organisational and disciplinary boundaries. As an example of ICT innovation in the Architecture, Engineering and Construction (AEC) industry, Building Information Modelling (BIM) is thought to play a boundary object role in collaboration. The literature, however, is less clear on how BIM technology as a boundary object is used for knowledge sharing in construction projects. This paper conceptualises BIM technology as a boundary object for collaboration in a construction project from a knowledge-as-practice perspective. The conceptual framework explains how BIM technology as tools and artefacts become boundary objects-in-use in a construction project collaboration. The paper demonstrates how this can further contribute to our understanding of knowledge sharing in construction projects as a boundary spanning practice among different backgrounds. As success within an increasingly digitalised society depends on ICT-based collaborations of diverse teams and professionals, a deeper understanding regarding such boundary objects-in-use can be particularly useful.

Keywords: Building Information Modelling (BIM) technology, boundary objects, knowledge.

1 Introduction

Building Information Modelling (BIM) is a set of digital tools and work process in construction projects for presenting the comprehensive building information through 3D digital models and databases across organisations and disciplines in the Architecture, Engineering and Construction (AEC) industry. This paper will argue that BIM can play the role of a boundary object in construction projects. Boundary objects are considered to be the device to facilitate the knowledge sharing among different fields. However, the project-based type work organisation in a construction project embodied in the temporary teams involves different parties increase the difficulty and challenge for knowledge sharing [3], making collaboration more challenging and problematic. There is thus fertile ground to explore effective collaboration thanks to the prevalence of project-based work from the AEC industry, which comprise members from multiple disciplines and organisations. Therefore, with the introduction of BIM in the AEC industry, there is an increased interest in the organisation of work practices for sharing knowledge in a construction project among team members from different organisations and disciplines [4–6].

BIM, regarded as a promising digital innovation, and increasingly used in innovative construction projects within the AEC industry, is thought to integrate different disciplines and organisations for better collaboration. Due to diverse professional backgrounds, understanding other team members' work often results in challenges and conflicts [4]. It is thus important to consider how to facilitate effective knowledge sharing for problem-solving and decision-making. Recent research calls for attention to studying BIM as a boundary object in construction project collaborations [7–10]. There is limited research exploring how the components of BIM technology can be conceptualised as boundary objects in a construction project, especially when knowledge sharing among professions is considered.

To provide a better understanding of BIM technology as a boundary object in a construction project, this paper proposes a conceptual framework to theorise the BIM components as boundary objects-in-use by identifying the role of BIM technology for collaboration among construction project team professionals. This is achieved, first, by determining the nature and characteristics of knowledge in the AEC industry and BIM technology as boundary objects through a literature review. Subsequently, we identify the elements of BIM technology in a construction project and determine the relationship between these concepts and boundary objects. Finally, we discuss the potential contribution this conceptual framing can make to the study of BIM as a boundary object and its role in boundary work around shaping collaborative practice in construction projects.

2 Literature Review

2.1 Knowledge-as-Practice Perspective in the Architecture, Engineering and Construction (AEC) Industry

Perspectives of Knowledge. Continuous debates in the literature about knowledge among scholars are taken from different perspectives. Most can be divided into either a knowledge-as-possessed-asset perspective or a knowledge-as-practice perspective. While the two perspectives come from different worldviews, Cook and Brown [11] suggest that possessed knowledge can be regarded as a tool to serve knowing as a process (i.e., part of action). From the perspective of knowledge as an ongoing process, Orlikowski [12] states that knowledge is an ongoing action embodied in what actors do every day to get their work done. Similarly, in other forms of work such as project-based organisational forms, e.g., in product development projects, Carlile's view [13] on knowledge also supports this perspective, i.e., that knowledge is not a static entity or stable disposition, but an ongoing and dynamic production among actors in innovative settings.

Knowledge in the AEC industry and Construction Project. A substantial amount of knowledge is involved in the AEC industry due to the many disciplines and organisations that contribute to different functions throughout the lifecycle of the same construction project. In the construction project collaborative process, knowledge can be shared through the interaction of different objects worlds [4], which include physical artefacts and tools as well as discipline-specific guidelines and associated practices. The transformation of different sharing pathways of explicit knowledge and tacit knowledge also indicates that knowledge and practice are inseparable [4]. Woo et al. [14] claim that shared knowledge in the construction project relies more on the AEC professions possessing tacit knowledge and their experience of related projects with explicit knowledge providing a supporting role and, in a project, knowledge is dynamic depending on problem-solving and the tasks to be performed. For the AEC industry, therefore, knowledge can be seen as a tool to facilitate a dynamic knowing process addressing problems to improve project progress. That means, therefore, in the ongoing construction project process, knowledge can be shared effectively when it can be used to achieve the practical targets and tasks in the actors' practice. In the construction project, Rezgui [15] classifies knowledge in the construction domain to include domain knowledge, organisational knowledge and project knowledge. Domain knowledge forms the overall information context, including administrative information, standards, technical rules and product databases. Organisational knowledge is company-specific, including personal skills, project experience of employees and cross-organisational knowledge. Project knowledge is the potential for usable knowledge created by interaction, including project records, solutions and memory of processes.

Using the knowledge-as-practice Perspective in Construction Projects. Knowing calls for an epistemology of practice, where practice implies doing the real work itself. Practice, here, refers to "action informed by meaning drawn from a particular group context" [11]. We understand knowing as the practice or 'doing' of actions using knowledge to seek a solution to a problem. To shed light on knowing in practice, Carlile's pragmatic view [13] suggests knowledge is localised, embedded, and invested in practice articulated from experience and know-how. Similar to this perspective, Ryle [16] proposes that know-how can be described as when a person knows how to do and that knowledge is manifested in their practice/action rather than in their statement.

Furthermore, the know-how practice/actions should be reasonable under the required principles of their work setting for performing their tasks. With respect to collaborative teams in the AEC industry, Majchrzak, Malhotra, and John [17] propose collaboration know-how in teams to refer to knowledge about how to communicate and integrate ideas with others and how to coordinate others' work and actions in the team. In light of the knowledge-as-practice perspective in collaboration within a construction project, digital technology also affects the knowing process among different functions. It is also suggested that knowledge-as-practice is embedded in the dynamics between physical interaction and ICT-related design practice in a construction project [4]. To apply the knowledge-as-practice perspective in a construction project, we need to draw on what actors in the construction project need to know and what actors are doing with what they need to know in practice.

2.2 Boundary Objects and Building Information Modelling (BIM)

The Nature and Characteristics of Boundary Objects. In the knowledge sharing process, knowledge is generally shared among different fields of practice and across boundaries. Boundaries delimit fields and arise from knowledge differences of different fields [18]. The objects used to facilitate the association between functions and across boundaries are defined as boundary objects that "are plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" [19]. Star [20] proposes three components of boundary objects: interpretive flexibility; the structure of informatics and work process needs and arrangements; and, finally, the dynamic between ill-structured and more tailored uses of the objects. Boundary objects are created or appear with several characteristics, participants share common goals but have different purposes and the shared goals are performed by each participant in different ways [19]; "boundary objects are at once temporal, based in action, subject to reflection and local tailoring" [20]. Based on different forms of boundary objects (repositories, ideal type, coincident boundaries and standardised forms) proposed by Star and Griesemer [19], Carlile [13] propose three approaches (i.e., transferring, translation, and transformation) that require capabilities to transfer and manage knowledge across syntactic, semantic and pragmatic boundaries. However, boundary objects might not be used to span boundaries as designated. Boundary objects are not always stable but are subject to change as part of actors' ongoing practice, such dynamic action leading to the emergence of a joint field of practice [21]. In knowledge sharing, artefacts can be transformed from a common

semantic meaning to a common pragmatic meaning for different functions involved in a joint field of practice thus leading to their reframing as boundary objects-in-use [21]. Boundary objects-in-use, they argue, are locally useful (incorporated into the joint practice) and have a common identity (recognisable across fields). Within the AEC industry, boundary objects may be devices that improve collaboration between different professions. Examples include timelines, building models, prototypes and sketches [22].

Building Information Modelling (BIM). BIM involves a set of digital modelling technologies used throughout a construction project's lifecycle to create, store, share, and reuse the integrated models of building information, associating different organisations and disciplines together. BIM-related collaboration entails generating, presenting and sharing information among various actors and project stakeholders [7]. From a boundary object perspective, BIM artefacts can be seen as potentially integrating knowledge from actors across different fields for problem-solving and decision-making during the project lifecycle. However, when actors possess knowledge from different backgrounds, Neff et al. [8] argue that the BIM digital models cannot actually work as boundary objects due to their failure to provide enough interpretative flexibility in communication. That means BIM artefacts may have design constraints that limit their ability to enable transference, translation or transformation of knowledge across boundaries. The implication is that even if BIM artefacts are thought to be designated boundary objects, their potential for knowledge sharing may only become evident as boundary objects-in-use [19, 21]. The interplay between BIM technology and BIM-enabled processes is inseparable, and BIM artefacts as boundary objects can influence collaboration and integration of activities in project teams in a structurational way, i.e., both in terms of the affordances of the technology and the way individual actors share knowledge and adjust their practices [7].

3 Conceptual Framing

BIM is regarded as the interplay of the BIM-enabled processes and BIM technology [7]. BIM technology includes BIM tools and BIM artefacts [9]. From a traditional software-view, BIM technology focuses on the relevant BIM tools including BIM-related hardware, software, and networks that help actors complete their work and achieve their goals [23]. BIM artefacts fall into five categories based on the project needs, i.e., digital models, 2D documents, specialised sessions, BIM execution protocols and decision-making instruments [24]. BIM tools and BIM artefacts are potential sources of boundary objects to achieve the collaboration needs of a construction project. The boundary objects used in a construction project consists of four types, including shared database, standardised format, property information representations and responsibility division. The proposed conceptual framework (Figure 1) consists of the main components of BIM technology and their relationship to boundary objects, within the context of AEC industry construction projects. Each part is further delineated below.

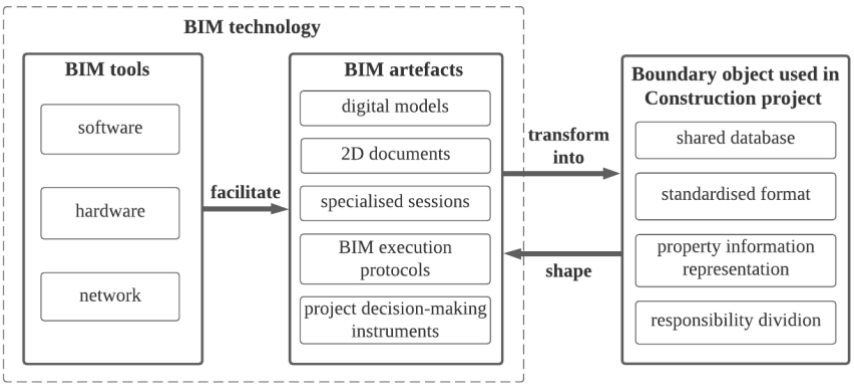

Fig. 1. The conceptual framework of the relationship between BIM technology and boundary objects in construction projects.

3.1 BIM Tools and BIM Artefacts

BIM technology consists of BIM tools and BIM artefacts. In construction projects, professionals produce BIM artefacts by engaging BIM tools through BIM-related software, hardware and networks. In this process, they contribute their knowledge from their professional background and experience from their work practice. For example, when architects create digital models of their ideas and visions for a project, they augment them with the documents that carry and communicate information from and to different stakeholders (such as the budgeting document from owners), forming together the contents of a shared database, which in turn becomes the basis for negotiating the design of the building. So the BIM tools engage with the professional's practice in producing the BIM artefacts. Furthermore, BIM technology in the construction project has multifaceted functions represented in the produced BIM artefacts in the lifecycle of a construction project, such as model integration and simulation. Digital models, i.e., 3D building models, are produced by different disciplines through diverse BIM software and other compatible tools. Procedural documents include 2D drawings and Gantt charts. Specialised sessions include clash detection and kick-off [7]; specialised sessions are for professionals who have different knowledge backgrounds to create a joint field of practice and deal with conflicts of digital information with each one specialised in their own fields providing professional solutions. BIM executive protocols include explicit conventional information to create BIM deliverables. Project decision-making instruments refer to the generated guidance for making decisions and progressing the project. Professional use of BIM tools to create, use and maintain BIM artefacts is embodied in BIM-enabled processes as part of the lifecycle of a construction project. Boundary objects need to represent the abstraction of construction management data in support of the use of an actor's tacit knowledge [25].

From current research on the nature of boundary objects, it is evident that boundary objects functioning effectively in practice require the emergence of a joint field that

embodies common meanings and values from different professions [20, 21]. In a construction project, BIM artefacts do not necessarily always become boundary objects even though they are often designated as able to bridge knowledge boundaries between the various professions [4]. When the tensions arising between the different professions' work practices lead to the recognition of growing problems, the BIM artefacts should perform roles with the effects of establishing the common language to transfer knowledge in their daily tasks and negotiation, helping to create the shared understanding in the collaboration, and enabling them to work together to develop the shared goals and creates new knowledge. These artefacts transform into the boundary object-in-use with both having the capacity of functioning effectively and providing the potential to facilitate the negotiation between different perspectives [13, 26]. Boundary Objects Used in the Construction Project

From existing research, generic types of boundary objects used in projects include repositories, standardised forms and methods, objects and models, and the map of boundaries [9]. The boundary objects influence the collaborative activities in a construction project in four aspects, i.e., searching and delivering information in the project; providing adaptable and universal elements to the teams it serves; bridging team members through creating balanced discussion and coordination, and clarifying the roles and responsibilities of project members [27]. Considering these effective roles in the construction project, boundary objects are used as shared databases, standardised formats, property information representations and responsibility divisions, respectively. Mapping BIM artefacts to generic types of boundary objects in construction projects shared databases can be seen as repositories that different professionals can access in their practice. For projects in the AEC industry, actors need to acquire and access both product knowledge and process knowledge through a shared lessons-learned database [28]. Similarly, standardised forms would refer to BIM artefacts that share a common language among professionals. This standardised information is crucial for communication among different specialisms in sharing information and knowledge, especially for standardising object models of buildings so that actors' knowledge of the project can be well-defined and shared through the modelling process [29]. Property information representation refers to types of objects and models in construction projects that satisfy the needs of professions in visualising building information to share their knowledge [25]. Responsibility division boundary objects are related to the map of boundaries. Through the demarcation of boundaries, professionals can identify their knowledge sharing. Responsibility division includes the concerns of actors' roles, duties and ways of working among professions to share knowledge in practice. Boundary objects, especially ICT-related boundary objects can depict and mediate this interaction among actors [30, 31].

The boundary objects-in-use also shape the BIM artefacts through the boundary process. Boundary objects-in-use can facilitate transformational learning since managing artefacts is not a static process in the project [9]. For example, BIM models as modifiable digital artefacts are also regarded as intermediary objects which are involved in the cycle of collaborative design [32]. In addition, the boundary objects-in-use can also shape the further BIM artefacts creating process (such as detailed design) through play a role of the object in the process (see Figure 1). For example, the project

ideas of the main structure from the early stage database might influence the latter detailed design in the fitting-out stage.

4 Discussion

BIM as an information system involves the interplay of BIM technology and BIM-enabled processes among professionals [7]. The previous section established a conceptual framework of the relationship between BIM technology and boundary objects by identifying the main BIM artefacts that can be regarded as boundary objects in construction projects and the main aspects of BIM tools that structure BIM artefacts. It illustrates the main types of boundary objects used in a construction project from the knowledge as practice view among AEC professionals. This conceptual framework provides some direction for further study on how BIM technology as a boundary object affects BIM-enabled processes.

According to Lindberg's [33] research, boundaries are performed in practice in an iterative and recursive way through boundary work. For BIM-enabled processes, interactions between professions are not always synchronised due to the characteristics of long-term modelling and frequent changes of needs or requirements from various parties. These processes share project information across different fields of practice or functions to integrate building information. Professionals work together to share knowledge for problem-solving and decision-making in the project. As new practices emerge, this shapes new boundaries, which in turn create opportunities for further new practices. This results in boundary work, i.e. a recursive relationship between practice and boundary and the iterative modelling process [33]. The inside of a boundary is composed of practice within the same professions, such as work based on documents, protocols and ideas of the profession. These are reflected on the outcomes directly (rather than the communication). The knowing process is more about explicit to explicit (e.g. sorting the records of on-site material usage) or tacit to explicit (e.g. architecture modelling). The difference, dependency and novelty can be manifested in how professions use relevant documents and protocols to achieve their tasks in their common fields. The inter-boundary interaction is more about tacit to tacit (e.g. sharing project experience), explicit to tacit (e.g. learning from the discussion), the difference, dependency and novelty can be explicated through conflicts and negotiation for decision-making. Therefore, the boundary work involved in BIM-enabled processes can be seen from two perspectives: work practice inside the boundaries of the profession (intra-boundary work) and work practice outside the boundaries of the profession (inter-boundary work).

4.1 BIM Artefacts as Boundary Objects within Professions and Professional's Know-how Practice -- Intra-Boundary Work

Within a profession's boundaries, actors' work practices include coordination and synchronisation in the same professions, such as individuals creating models according to the needs and requirements of other parties or policies. BIM artefacts can be created,

used or delivered under contracts and relevant instructions between agents [7]. Therefore, when actors use BIM tools to complete their professional work or achieve a goal, their know-how practice is influenced by the requirements and needs of other parties via policies and contracts. Know-how practice can also be seen as the actor's process of completing their work from 'objects' (the artefacts that individuals work with) to 'ends' (the outcomes that substantiate the successful creating, measuring and manipulating of the objects) [13]. In the light of the process from 'objects' to 'ends' in the lifecycle of a construction project, BIM is seen as playing a role in know-how practice [4], such as the BIM model being used as a boundary object and BIM-related software helping actors to complete their work.

Know-how practice is thus a form of collaborative work in construction projects. Knowledge sharing occurs through know-how practice among individuals in construction projects. It is expected that individuals' knowledge will be transferred and shared when collaborating with others through interaction and boundary objects. Neff [8] suggests, though, that digital objects have less interpretative flexibility, leading to nominated boundary objects failing to bridge boundaries effectively. This result also verifies the proposition from existing research [21] that not all boundary objects can actually play the boundary objects-in-use role. In addition, change always happens in a construction project so that BIM artefacts designated as boundary objects might not achieve the function of boundary-object-in-use. Thus, for BIM artefacts to become boundary objects-in-use may require BIM artefacts to encompass know-how practice from 'objects' to ends. For example, BIM modellers may integrate BIM models from different design disciplines into a whole in order to detect design issues. There are some discussion on the intra-professional relation [34] and various forms of work occur at the intra-professional level [35]. Thus far, however, only few studies have considered how boundary objects play a role in the intra-boundary work, particularly regarding BIM artefacts used as boundary objects in construction projects. This work provide a insight to explore how BIM artefacts designated as boundary objects involved in intra-boundary work practice emerge as boundary objects-in-use and how professionals shape know-how practice with BIM in a project.

4.2 BIM Artefacts as Boundary Objects in Knowledge Sharing Practice Between Professionals -- Inter-Boundary Work

Representing knowledge, learning difference and dependency at knowledge boundaries and jointly transforming current knowledge into a common field should be achievable through boundary objects [13, 21]. Interactions among actors who have different professional backgrounds in a construction project always involve knowledge embedded in practice. Work practices outside of professional boundaries, i.e., inter-boundary interaction, includes synchronised communication and negotiation with other professions. Therefore, it is significant and worthwhile to explore how the dynamic relationship between practice and the boundary is influenced by BIM artefacts, as boundary objects. Few studies explore how boundary objects are represented, understood or used in boundary work across knowledge boundaries in the AEC industry. Earlier studies have shown how the establishment of digital artefacts' value

and local usefulness can situate them as boundary objects in the effective knowledge boundary spanning [6, 33]. The same can be explored in the context of BIM artefacts' use in effective knowledge boundary spanning.

Current research focuses less on BIM-enabled processes, especially the knowledge sharing aspects [36]; thus it is important to establish the relationship between BIM-enabled processes, knowledge sharing, knowledge boundaries and collaborative practice [37]. The proposed conceptual framework provides a foundation to study BIM as a boundary object involved in digital collaboration in the context of a BIM-enabled project from the knowledge-as-practice perspective. BIM artefacts as boundary objects can play a role in the boundary work occurring at knowledge boundaries between professions. Effective boundary objects should provide the transferring, translating and transforming capacities to approach different boundaries [13]. In addition, as Levina and Vasst [21] argue, when new joint fields of practice emerge that incorporate a common meaning from, say the negotiation related to problem-solving, boundary objects may have a transformative effect to guide in making decisions. Thus, through exploring the relationship between BIM and boundary objects, it enhances the understanding of the capacity of BIM as a boundary object to navigate and shape knowledge boundaries between different fields of practice in a construction project and the construction of a new collaborative practice.

5 Conclusion

Recent research on BIM collaboration focuses more on managing boundaries through discussing the influence of BIM as a boundary object in the collaboration [7, 9, 31], but less on how BIM technology is regarded as a boundary object. For future empirical research work, the conceptual framework developed in this paper helps explore BIM-enabled construction projects in practice. At the project level, the framework can explore how BIM influences knowledge boundary work, and knowledge sharing, thus helping project managers consider BIM implementation and its influence on work practice. Furthermore, managers can improve their competence by considering BIM-related training and education at the organisational level. These studies can also help institutions interpret BIM-related instructions and protocols at the industry level. Overall, this work brings to the fore insights regarding BIM as a boundary object among team members from different professional backgrounds, but the lack of the guideline on how to conduct empirical research or design science research is the limitation of this work.

This paper contributes to knowledge by exploring the relationship between BIM technology and boundary objects in a construction project. The framework contributes to addressing the gap around how BIM artefacts as boundary objects involved in the boundary work involving collaborative practices and how BIM artefacts as boundary objects can establish know-how practice from 'objects' to 'ends' in a construction project. Having said that, the study's findings are particularly pertinent for our increasingly digitalised society. Focusing on boundary work and collaborative practices, the study's arguments can be extrapolated to other settings where project

success depends on the collaboration of diverse team members of different backgrounds and the use of boundary objects, as for example distributed teams assembled on an ad hoc basis for a software or research project.

References

1. Mignone, G., Hosseini, M.R., Chileshe, N., Arashpour, M.: Enhancing collaboration in BIM-based construction networks through organisational discontinuity theory: a case study of the new Royal Adelaide Hospital. Architectural Engineering and Design Management. 12, 333–352 (2016). https://doi.org/10.1080/17452007.2016.1169987
2. Oesterreich, T.D., Teuteberg, F.: Behind the scenes: Understanding the socio-technical barriers to BIM adoption through the theoretical lens of information systems research. Technological Forecasting and Social Change. 146, 413–431 (2019). https://doi.org/10.1016/j.techfore.2019.01.003
3. Dave, B., Koskela, L.: Collaborative knowledge management—A construction case study. Automation in Construction. 18, 894–902 (2009). https://doi.org/10.1016/j.autcon.2009.03.015
4. Berente, N., Baxter, R., Lyytinen, K.: Dynamics of inter-organisational knowledge creation and information technology use across object worlds: the case of an innovative construction project. Construction Management and Economics. 28, 569–588 (2010). https://doi.org/10.1080/01446193.2010.489926
5. Doolin, B., McLeod, L.: Sociomateriality and boundary objects in information systems development. European Journal of Information Systems. 21, 570–586 (2012). https://doi.org/10.1057/ejis.2012.20
6. Hsu, J.S.-C., Chu, T.-H., Lin, T.-C., Lo, C.-F.: Coping knowledge boundaries between information system and business disciplines: An intellectual capital perspective. Information & Management. 51, 283–295 (2014). https://doi.org/10.1016/j.im.2013.12.005
7. Papadonikolaki, E., van Oel, C., Kagioglou, M.: Organising and Managing boundaries: A structurational view of collaboration with Building Information Modelling (BIM). International Journal of Project Management. 37, 378–394 (2019). https://doi.org/10.1016/j.ijproman.2019.01.010
8. Neff, G., Fiore-Silfvast, B., Dossick, C.S.: A Case Study of the Failure of Digital Communication to Cross Knowledge Boundaries in Virtual Construction. Information, Communication & Society. 13, 556–573 (2010). https://doi.org/10.1080/13691181003645970
9. Forgues, D., Koskela, L.J., Lejeune, A.: Information technology as boundary object for transformational learning. Journal of Information Technology in Construction. 14, 48–58 (2009)
10. Merschbrock, C., Munkvold, B.E.: A Research Review on Building Information Modeling in Construction—An Area Ripe for IS Research. CAIS. 31, (2012). https://doi.org/10.17705/1CAIS.03110
11. Cook, S.D.N., Brown, J.S.: Bridging Epistemologies: The Generative Dance Between Organizational Knowledge and Organizational Knowing. Organization Science. 10, 381–400 (1999). https://doi.org/10.1287/orsc.10.4.381

12. Orlikowski, W.J.: Knowing in Practice: Enacting a Collective Capability in Distributed Organising. Organization Science. 13, 249–273 (2002). https://doi.org/10.1287/orsc.13.3.249.2776
13. Carlile, P.R.: A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. Organization Science. 13, 442–455 (2002). https://doi.org/10.1287/orsc.13.4.442.2953
14. Woo, J.-H., Clayton, M.J., Johnson, R.E., Flores, B.E., Ellis, C.: Dynamic Knowledge Map: reusing experts' tacit knowledge in the AEC industry. Automation in Construction. 13, 203–207 (2004). https://doi.org/10.1016/j.autcon.2003.09.003
15. Rezgui, Y.: Review of information and the state of the art of knowledge management practices in the construction industry. The Knowledge Engineering Review. 16, 241–254 (2001). https://doi.org/10.1017/S026988890100008X
16. Ryle, G.: Knowing How and Knowing That: The Presidential Address. Proceedings of the Aristotelian Society. 46, 1–16 (1945)
17. Majchrzak, A., Malhotra, A., John, R.: Perceived Individual Collaboration Know-How Development Through Information Technology–Enabled Contextualisation: Evidence from Distributed Teams. Information Systems Research. 16, 9–27 (2005). https://doi.org/10.1287/isre.1050.0044
18. Fox, J.L., Cooper, C.: Boundary-Spanning in Organisations: Network, Influence and Conflict. Routledge (2013)
19. Star, S.L., Griesemer, J.R.: Institutional Ecology, `Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Soc Stud Sci. 19, 387–420 (1989). https://doi.org/10.1177/030631289019003001
20. Leigh Star, S.: This is Not a Boundary Object: Reflections on the Origin of a Concept. Science, Technology, & Human Values. 35, 601–617 (2010). https://doi.org/10.1177/0162243910377624
21. Levina, N., Vaast, E.: The Emergence of Boundary Spanning Competence in Practice: Implications for Implementation and Use of Information Systems. MIS Quarterly. 29, 335–363 (2005). https://doi.org/10.2307/25148682
22. Koskela, L., Pikas, E., Gomes, D., Biotto, C., Talebi, S., Rahim, N., Tzortzopoulos, P.: Towards Shared Understanding on Common Ground, Boundary Objects and Other Related Concepts. In: Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, 20-22 July 2016. pp. 63–72. , Boston, USA (2016)
23. Succar, B.: Building information modelling framework: A research and delivery foundation for industry stakeholders. Automation in Construction. 18, 357–375 (2009). https://doi.org/10.1016/j.autcon.2008.10.003
24. Papadonikolaki, E., Vrijhoef, R., Wamelink, H.: The interdependences of BIM and supply chain partnering: empirical explorations. Architectural Engineering and Design Management. 12, 476–494 (2016). https://doi.org/10.1080/17452007.2016.1212693
25. Russell, A.D., Chiu, C.-Y., Korde, T.: Visual representation of construction management data. Automation in Construction. 18, 1045–1062 (2009). https://doi.org/10.1016/j.autcon.2009.05.006
26. Franco, L.A.: Rethinking Soft OR interventions: Models as boundary objects. European Journal of Operational Research. 14 (2013)

27. Phelps, A.F., Reddy, M.: The influence of boundary objects on group collaboration in construction project teams. In: Proceedinfs of the ACM 2009 international conference on Supporting group work - GROUP '09. p. 125. ACM Press, Sanibel Island, Florida, USA (2009)
28. Ferrada, X., Núñez, D., Neyem, A., Serpell, A., Sepúlveda, M.: A Lessons-learned System for Construction Project Management: A Preliminary Application. Procedia - Social and Behavioral Sciences. 226, 302–309 (2016). https://doi.org/10.1016/j.sbspro.2016.06.192
29. Howard, R., Björk, B.-C.: Building information modelling – Experts' views on standardisation and industry deployment. Advanced Engineering Informatics. 22, 271–280 (2008). https://doi.org/10.1016/j.aei.2007.03.001
30. Bosch-Sijtsema, P., Gluch, P.: Challenging construction project management institutions: the role and agency of BIM actors. International Journal of Construction Management. 1–11 (2019). https://doi.org/10.1080/15623599.2019.1602585
31. Gal, U., Lyytinen, K., Yoo, Y.: The dynamics of IT boundary objects, information infrastructures, and organisational identities: the introduction of 3D modelling technologies into the architecture, engineering, and construction industry. European Journal of Information Systems. 17, 290–304 (2008). https://doi.org/10.1057/ejis.2008.13
32. Miettinen, R., Paavola, S.: Reconceptualising object construction: the dynamics of Building Information Modelling in construction design. Information Systems Journal. 28, 516–531 (2018). https://doi.org/10.1111/isj.12125
33. Lindberg, K., Walter, L., Raviola, E.: Performing boundary work: The emergence of a new practice in a hybrid operating room. Social Science & Medicine. 182, 81–88 (2017). https://doi.org/10.1016/j.socscimed.2017.04.021
34. Martin, G.P., Currie, G., Finn, R.: Reconfiguring or reproducing intra-professional boundaries? Specialist expertise, generalist knowledge and the 'modernisation' of the medical workforce. Social Science & Medicine. 68, 1191–1198 (2009). https://doi.org/10.1016/j.socscimed.2009.01.006
35. Comeau-Vallée, M., Langley, A.: The Interplay of Inter- and Intraprofessional Boundary Work in Multidisciplinary Teams. Organisation Studies. 41, 1649–1672 (2020). https://doi.org/10.1177/0170840619848020
36. Cao, D., Li, H., Wang, G., Luo, X., Yang, X., Tan, D.: Dynamics of Project-Based Collaborative Networks for BIM Implementation: Analysis Based on Stochastic Actor-Oriented Models. Journal of Management in Engineering. 33, 1–12 (2017). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000503
37. Deshpande, A., Azhar, S., Amireddy, S.: A Framework for a BIM-based Knowledge Management System. Procedia Engineering. 85, 113–122 (2014). https://doi.org/10.1016/j.proeng.2014.10.535