THE ROLE OF BIM IN PREVENTING DESIGN ERRORS

Peter Johansson[1], Henrik CJ Linderoth and Kaj Granth

University of Jönköping, School of Engineering, P.O Box 1026, SE-551 11 Jönköping, Sweden

Design errors are claimed to account for 26% of the cost of defects, these in turn are stated to encompass 2-9% of production cost for building and constructions. Lack of knowledge and information has been identified as a major reasons for design errors. Recently Building Information Modelling (BIM) has been considered as a mean for reducing design errors. However, limited research has been conducted on the role of BIM as a means for transfer and sharing knowledge in order to reduce design errors. The aim of the paper is to analyse BIM's role of facilitating knowledge and expertise sharing in order to prevent design errors. The aim is achieved by analysing a case study of design errors in a construction project. By drawing on the concept of boundary object it is confirmed that BIM can serve a mean for preventing design errors by facilitating knowledge and expertise sharing, across discipline, time and space, and professional boundaries. Depending the kind of boundary knowledge and expertise should be shared across, different challenges emerge in organizing the knowledge and expertise sharing

Keywords: design error, BIM, boundary objects, knowledge sharing.

INTRODUCTION

Design errors are claimed to account for 26% of the cost of defects. Cost of defects are in turn stated to encompass 2-9% of production cost for building and constructions (Josephsson and Hammarlund, 1999). The sharing of knowledge and information can be assumed to play a pivotal role for the reduction of design errors, because lack of knowledge and information has been identified as a major reasons for design errors. In their study, Josephson and Hammarlund (1999) show that design errors were mainly caused by lack of knowledge (44%), lack of motivation (35%), lack of information 18%, and risk and stress (3%).

A variety of approaches and methods for reducing design errors have been suggested, and recently building information modelling (BIM) has been considered as a mean for reducing design errors, for example by automated clash detections and that visualization enhance peoples understanding of what an accomplished building, or construction would look like(see e.g Jongling, 2008). In this sense BIM can play a pivotal role as a mean for transfer and sharing of knowledge and information that has a potential for reducing design errors. However, limited research has been done on the role of BIM as a means for transfer and sharing knowledge and information in general. A few papers have been published on BIM and knowledge, for example BIM in the maintenance stage (Motawa and Almarshad, 2013) and BIM for knowledge sharing by feedback (Ho *et al*, 2013). On the other hand is there a rich body of

[1] henrik.linderoth@jth.hj.se

Johansson, P, Linderoth, H C J and Granth, K (2014) The role of bim in preventing design errors *In:* Raiden, A B and Aboagye-Nimo, E (Eds) *Procs 30th Annual ARCOM Conference, 1-3* September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 703-712.

literature on the transfer and sharing of knowledge in project based organizations to draw upon when the role of BIM as a means for transfer and sharing of knowledge should by analysed. In this literature the constraints on ICT's capabilities to capture and codify knowledge have long been recognized (Fahey and Prusak 1998), when taking into consideration the embeddedness of knowledge in organizational systems and processes, and the fact that knowledge is embodied in skills and competencies of groups and individuals (Blacker, 1995). Basically, the problems revolves around the sharing and transfer of explicit, respectively tacit knowledge, and making the tacit knowledge explicit.

In the literature on computer supported cooperative work (CSCW) the idea that tacit knowledge can be made explicit has been criticized (see e.g. Ackerman *et al* 2013). Ackerman *et al* (2013) argue that Nonaka and Takeuchi's (1995) interpretation of Polyani's (1967) terminology of tacit and explicit knowledge, nurtured the idea that tacit knowledge can be made explicit, which also could be design goals associated with IT tools, but Ackerman *et al* state that the term *"tacit"* exactly describes that certain kind of knowing is difficult, if not impossible to verbalize. Research on CSCW have moved away from the distinction between tacit and explicit when knowledge sharing is discussed and instead used the concepts knowledge sharing and expertise sharing. When knowledge sharing is discussed the externalization of knowledge in the form of computational or information technology artefacts or repositories play an important role. Whereas in expert sharing the capability to get the work done or to solve a problem is instead based on discussions among knowledgeable actors and less significantly supported by a priori externalizations (Pipek *et al*. 2012; Ackerman *et al*. 2002). Against this background the aim of the paper is to analyse BIM's role of facilitating knowledge and expertise sharing in order to prevent design errors.

It should be noted that by using the concepts knowledge- and expertise sharing we follow Ackerman *et al* (2013) who not differentiate between knowledge and information and state that *"We could easily spend several lifetimes teasing the two apart, and colloquial uses are sufficient (as argued in Normark and Randall 2005)"* (Ibid: 562).

THE MANAGEMENT OF KNOWLEDGE IN PROJECT BASED ORGANIZATIONS

The development of knowledge transfer capabilities between projects, or to the permanent organization has been recognized as a critical competence for organizations in order to achieve competitive advantages (Nonaka 1994, Scarborough *et al*. 1999). In the quest for the supporting factors for the management of knowledge, early debates had a tendency to focus on the use of information and communication technologies as means for knowledge transfer between projects (Cole-Gomolski 1997, Finerty 1997). But it is well known that ICT's capabilities constrains the capture and codifying of knowledge (Fahey and Prusak 1998). In order to overcome knowledge transfer barriers, research has recognized a range of interventions taking into consideration the embeddedness of knowledge in organizational systems and processes, or the fact that knowledge is embodied in skills and competencies of groups and individuals (Blacker, 1995). These interventions can be classified along a continuum from cognitive to community models of the management of knowledge (Swan *et al* 1999). In the cognitive models the codification of knowledge and its transfer within the organization is primarily emphasized (Cole-Gomolski 1997). The codification of knowledge takes place e.g. by process-based or documentation-based debriefing methods where experiences from projects are recorded (see e.g. Schindler and Eppler 2003). However, the assumptions the cognitive approach is built on have been challenged by questioning the bias towards explicit knowledge and possibilities of codifying knowledge and inscribing it into an information system (Spender 1996, Tsoukas 1996). In the community model of knowledge transfer, the focus is on the tacit dimension of knowledge and its embeddedness in social groups (Szulanski 1996). However, there are difficulties in exploiting this knowledge because it is dependent on someone else having shared interpretive schemes that enable the understanding and acceptance of the knowledge (Schwenk 1988). Accordingly, the transfer of the tacit knowledge is dependent on the development of some level of shared interpretive schemes allowing a group to understand and apply another group's knowledge in their own setting (Senge 1990, Weick 1995), and in that way create a community of practice (Brown and Duguid 1991, 2001). In communities of practice the transfer and application of knowledge is very much dependent on the situatedness and context of practice (Pavitt 1984), which causes organizational challenges in a project context where groups are temporally and spatially differentiated, and task focused (see e.g. Bresnen *et al*. 2004). Thus, the organizational challenge lies in working out the organizing of social practices and the alignment of them (Brown and Duguid 2001).

Accordingly, how can we understand affordances BIM provide for organizing a social practices these would facilitate knowledge and expertise sharing? Some authors has labelled BIM as a boundary object (see e.g. Gal *et al*, 2008; Whyte and Lobo, 2010; Neff *et al*, 2010). Boundary objects are *"objects which both inhabit several intersecting social worlds and satisfy the informational requirements of each of them. Boundary objects are objects which are plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites."* (Star and Griesemer, 1989: 393). Boundary objects act as 'anchors or bridges, however temporary' across different groups with different goals, objectives, and purposes (ibid:414). Thus, BIM as a boundary object provides a mechanism for a reciprocal knowledge sharing among professional groups (Whyte and Lobo, 2010). However, several scholars have argued that boundary objects are most effective for collaboration and coordination when they are actual objects – tangible and concrete, but still able to maintain multiple, epistemic definitions so as to be accepted and usable by the groups they are trying to bridge (Carlile 2002; Bechky 2003). They help people work across knowledge boundaries through assisting with the processes of 'transferring, translating, and transforming' (Carlile 2004). Neff *et al* (2010:569) argue that boundary objects are useful when they can produce interpretive flexibility across heterogeneous knowledge boundaries, but BIM and the practices around BIM are not currently producing the socio-technical conditions for this flexibility. Deeply embedded disciplinary thinking is not easily overcome by digital representations of knowledge and that collaboration may be hindered through the exposure of previously implicit distinctions among the team members' skills and organizational status (ibid). However, in the case referred, the issue is if BIM fail to play the role as a boundary object, or if the deeply embedded disciplinary thinking not allowed BIM to take the role as a boundary object?

In the literature on CSCW, the view on BIM as a boundary object, is classified in the so called repository model, belonging to the first generation of research in CSCW, where management of information is concerned with information as an externalized artifact, or object, although information has to be understood within a social context (Ackerman *et al*, 2013). The second generation of research has been more people centric and labelled expert sharing, meaning the capability to get the work done or to solve a problem based on discussions among knowledgeable actors and less significantly supported by a priori externalizations. Emphasis was on finding an appropriate person, and sharing tacit knowledge, including that contextual knowledge that might be required to understand information is critical (ibid). Technologies should support expertise sharing by finding people and locate expertise. Taking this two generations of research into consideration, it can be claimed that BIM could be an object for study when it comes both to repository models, as well as expertise sharing.

METHOD AND CASE DESRIPTION

In order to achieve the aim of the paper a case study of a construction project has been analyzed. The case is the fifth wing that is an enlargement of one of the university buildings at Jönköping University, Sweden. The building is a five story split level house with a total area of 3000m2, containing offices and lecture halls. It was built during 2003 and 2004. The production cost was about 55 million SEK or 5.9 million Euro. The type of contract used was general contract. Both the construction manager and the structural engineer agreed that this project went well and there were no major problems in the project. The structure of the building is prefabricated concrete and the structural engineers used ordinary 2D technique (AutoCAD) in the design of the building.

The case study was conducted in two major phases. In the first phase design errors were detected and categorized. In the second phase the building was modeled by using Tekla-structures (www.tekla.com) in order to able to investigate if a product-model based technique could be a mean for reducing design errors.

In the first phase data was collected by three sources: drawings, construction deficiency reports, and informal interviews. The drawings were studied to get an understanding of the project and to get a geometrical description and the material of the structure. The type of contract, general contract, made construction deficiency reports available. By studying the construction deficiency reports, the design errors causing some of the deficiency reports could be identified. A number of informal interviews with the construction manager, who was the author of most of the construction deficiency reports, and the structural engineer were also conducted. The purpose of these interviews was to gain a better understanding of some of the deficiencies.

Based on the information gathered, the next step performed was to analyze the construction deficiencies in the following steps:

Design error? Yes/No

If yes:

Participants involved?

Are errors situated were two or more element meet? (Yes/No)

It was noticed early in the case study that most of the defects reported in the construction deficiency reports were situated where two or more elements met. To confirm this finding it was investigated for each defect if it was situated were two or more element met.

The design errors were in turn categorized according to which participants that were involved in the design errors. The design errors where the structural engineer was involved (SE-errors) were investigated further. The reason for choosing design errors related to structural engineering was that one of the authors has a background in structural engineering, which was an advantage in the further investigation of the data.

In the second phase each SE-error was further investigated with help of the developed Tekla model of the building in order to answer the following questions:

Could SE-error be avoided using product-model based CAD-system? Yes/No

Could SE-error be avoided in the next project using feedback? Yes/No

However, the following results should not be interpreted as SE-errors per default are avoided if a product-model based CAD-system and feedback are used in the next project. Instead, the results should be interpreted as option for avoiding SE-errors if a product-model based CAD-system and feedback is used. However, already now it can be realized that options are more or less easy to take advantage of. For example, in this stage it can be assumed it is rather easy to prevent clashes in filed installations by taking advantage of automated clash controls, compared to error prevention that require interactions and expertise exchange among designers. Nevertheless, how options can be explored is discussed in the discussion section.

RESULTS

In total, 185 construction deficiency reports were studied and categorized. 57% (106) of these construction deficiencies were categorized as design errors while 43% were caused by other reasons. The involvement of the different participants in these design errors were:

Architect	19%
Structural engineer	30%
HVAC engineer	68%
Electrical engineer	37%

The HVAC engineer was the designer involved in most of the design errors, 68% (72) and the structural engineer was involved in 30% (32) of the design errors. We will focus on these design errors and they are from now on called SE-errors.

24 (75%) of the 32 SE-errors involved other participants
26 (82%) of the 32 SE-errors were situated were two or more element met

Thus the very majority of SE-related design errors involves other participants, or situations when two or more elements meet, or both. Below three examples of design errors are presented and these could have been avoided by the use of BIM as a means for visualization and clash detection, and feed back.

First, a partition wall should contain HVAC-installations. These installations have to be transferred trough the hollow core to the lower floor. Due to the placement of the partition wall a hole through the hollow core would result in cutting the strand and in turn reduce the resistance of the hollow core (Figure 1). This problem was found on site when the wall had been half built and the HVAC-installations should be put in place. It was decided necessary to move the wall, causing a great amount of extra work and cost. This error could have been avoided by visualization of the design solution.

Second, the combining of the pile foundation and the spread foundation resulted in a very thick concrete section that implied a longer drying time of the concrete (Figure

2). Even if heating hoses was embedded in the concrete the drying time became longer than expected, resulting in a delay of laying a plastic carpet. This could have been avoided if feed-back had been available, informing that a plastic film could have been placed between the pile foundation and the spread foundation. See also figure 4.

Third, the architect had designed the attachment of in-fill walls in the same mode in the whole building, but the SE-had designed two different solution at different floors, where one of the solutions were directly in-appropriate (Figure 3).

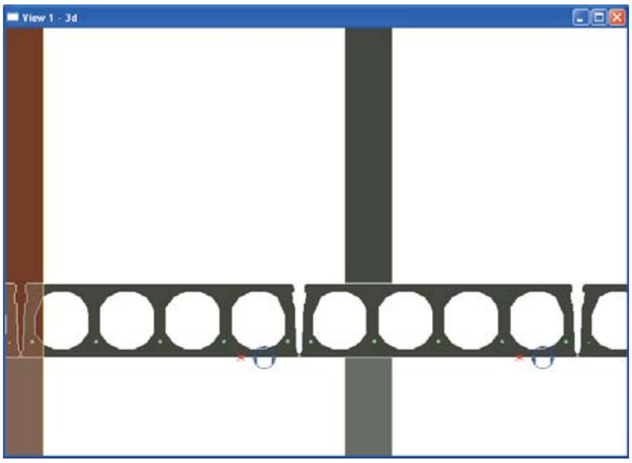

Figure 1: A faulty placement of a partition wall could have been avoided if BIM had been used, thanks to better visualization possibilities.

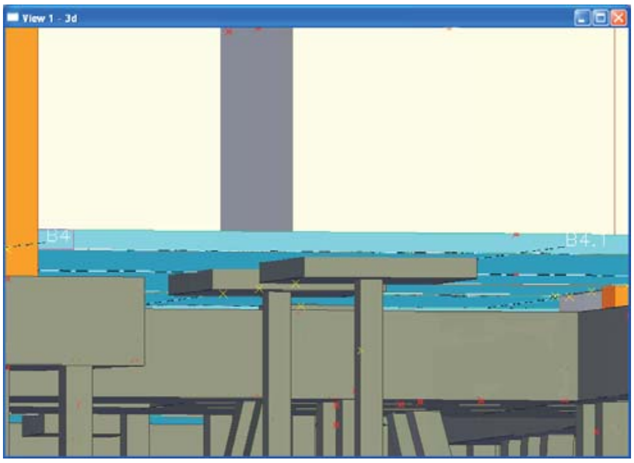

Figure 2: The combining of the pile foundation and the spread foundation.

15 (47%) of the 32 SE-errors were categorized as *"Could be avoided using product-model based CAD-system"* That is, they could probably have been avoided if a product-model based CAD-system had been used in the design process. 8 of these 15 errors also involved the HVAC engineer. For example was a solution designed for the heating system along the outer walls that implied that the tubes should go through the concrete beam.

12 (38%) of the 32 SE-errors were categorized in the category *"Could be avoided in the next project using feedback"*. Of these 12 SE-errors, as many as 11 (92%) were situated where two or more element met.

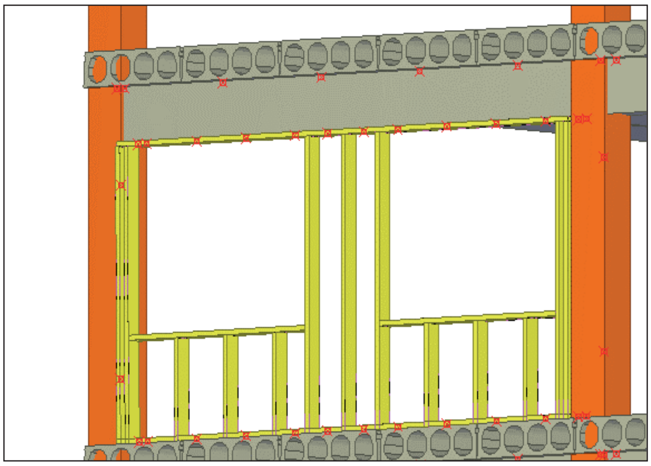

Figure 3: In-appropriate attachment of in-fill walls.

If the two techniques, both product-model based CAD-system and feedback, were successfully used, 20 (63%) of the 32 SE-errors could have been avoided.

Finally we want to show an example of how the feedback information can be made available to the structural engineer, using product-model-based CAD-systems. We then designed a prototype to show how this information could be made available by using a product model in the way that the construction deficiency reports were linked to the elements involved. The construction deficiency reports were created using Microsoft Word. These reports were translated to HTML documents. Having this, the construction deficiency reports could in the prototype be connected to the elements by giving the URL to the HTML document. In the prototype the document is situated in a subdirectory of the project file but it could be placed in a database. The product model is then transferred to the structural engineer, or a common web-based product model could be used. The structural engineer can then browse the elements and study the construction deficiency report together with the elements involved (Figure 4).

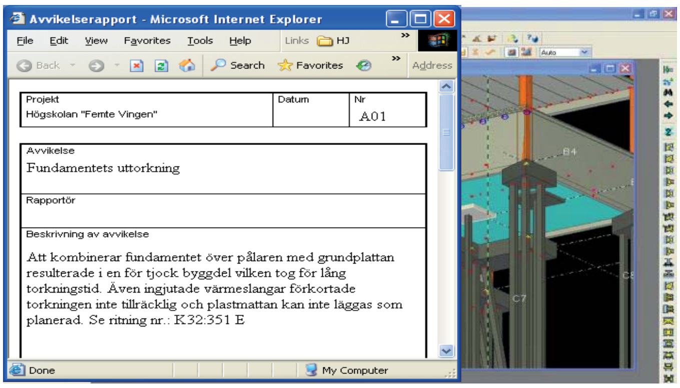

Figure 4: The structural engineer can now browse the elements and investigate the construction deficiency report and the elements involved.

DISCUSSION

The aim of the paper has been to analyse BIM's role in facilitating knowledge and expertise sharing in order to prevent design errors. Based on the case study it is confirmed that BIM can serve a mean for preventing design errors by facilitating knowledge and expertise sharing. By drawing on the idea of BIM as boundary object, BIM serve a means for preventing design errors by facilitating knowledge and expertise sharing across different boundaries. By paying attention to the kinds of boundaries crossed, challenges in the organizing of knowledge and expertise sharing can be detected. By drawing on three examples from the case study it can be claimed that three modes of error preventions can be identified.

The first mode, intrusion over of disciplinary boundaries, that encompass the traditional clash detections, is where two or more element meet and where more disciplines are involved (see for example figure 1 and 4). Either by automated clash detections, or visual inspection BIM provides actors with information that the actual design solution cannot be implemented. This kind of problems is solved by a discussion among actors who had become more knowledgeable due to the visual representation and in the next step can agree upon a revised design solution. This mode of preventing design errors can be claimed to be rather uncomplicated, because BIM makes the intrusion over disciplinary boundaries rather visible and the organizing of solving the error is made by communication among the disciplines involved in order find a revised design solution.

In the second mode, knowledge sharing across time- and space boundaries, concerns design errors these occurs due to lack of knowledge of what for example happens when two elements meet (see for example figure 2). This mode of knowledge sharing is somewhat more complex than the first mode. The knowledge is explicit, but the organising of knowledge sharing over time and space is somewhat more challenging, because roles and responsibilities are more blurred. This is a classical knowledge management problem. Knowledge about a potential problem and solution of the problem is somewhere inside or outside the organization, but there is no match making between to knowledge and the actor in need of the specific knowledge. Challenges in the organizing of the knowledge sharing is first who should document the knowledge and where should it would be transferred? Second, who is responsible for attaching the information to the right elements, if the knowledge concerns measure to be taken when two or more elements meet, as in the case with the plastic film? Third, who is responsible for making the information in the model available in the next project?

In the third mode, expertise sharing across professional boundaries, concerns design errors these are related to forms and functions, and requires the involvement of actors from more disciplines. This mode of error prevention draws on BIM’s visualizing capabilities. But in the first mode actors from a similar community of practice can immediately make sense of a visualized clash between two elements and the further consequences without any further communication. In this, mode, however, one involved actor make sense of a visualized design solution that s/he not finds appropriate (see for example figure 3). With help of the model and communication with other actors involved, the actor who finds a design solution inappropriate can explan wha s/he finds the solution inappropriate. Regardless if actors concerned can make sense of the problem, or find it crucial, thanks to the visualization they contribute to a revised design solution. The organizing of this mode of error prevention can be more, or less complex. The less complex organizing is that design errors are detected in regular design meeting and finding an acceptable revised design solution can be more or less complex. An alternative way to avoid design errors from the outset, is to transform the organizing of design from a sequential organizing of design activities, to a more integrated and concurrent design process where these errors not appear. However, this solution is more complex from the perspective of organizing the design and construction process. A more integrated and concurrent design process would probably require a changed procurement process that is outside to scope of this paper, but a topic for future research.

CONCLUSIONS

Based on the case study it is confirmed that BIM can serve a mean for preventing design errors by facilitating knowledge and expertise sharing, across discipline, time and space, and professional boundaries. Depending the kind of boundary knowledge and expertise should be shared across, different challenges emerge in organizing the knowledge and expertise sharing.

REFERENCES

Ackerman, M S, Pipek, V and Wulf, V (eds.) (2002) Sharing Expertise: Beyond Knowledge Management. Cambridge, MA: MIT Press).

Ackerman, M S, Pipek, V and Wulf, V (eds.) (2002) Sharing Expertise: Beyond Knowledge Management. Cambridge, MA: MIT Press.

Ackerman, M., Dachtera, J., Pipek, V., and Wulf, V (2013) Sharing Knowledge and Expertise: The CSCW View of Knowledge Management. *"Computer Supported Cooperative Work"*, **22**(4), 531-573.

Bechky, B.A. (2003) Object lessons: workplace artifacts as representations of occupational jurisdiction. *"American Journal of Sociology"*,**109**(3), 720–752.

Blackler, F (1995) Knowledge, knowledge work and organisations: an overview and interpretation. *"Organisation Studies"*, **16**(6), 1021–1046.

Bresnen, M, Goussevskaia, A, and Swan, J (2004) Embedding new management knowledge in project-based organizations. *"Organization Studies"*, **25**(9), 1535–1555.

Brown, J S and Duguid, P (1991) Organizational learning and communities-of-practice: toward a unified view of working, learning and innovation. *"Organization Science"*, **2**(1), 40–57.

Brown, J S and Duguid, P (2001) Knowledge and organization: a social practice perspective. *"Organization Science"*, **12**, 198–213.

Carlile, P R (2002) A pragmatic view of knowledge and boundaries: boundary objects in new product development. *"Organization Science"*, **13**(4), 442–455.

Carlile, P R (2004) Transferring, translating and transforming: an integrative relational approach to sharing and assessing knowledge across boundaries. *"Organization Science"*, **15**(5), 555–568.

Cole-Gomolski, B (1997) Users loathe to share their know-how. *"Computerworld"*, 31(46), 6.

Fahey, L and Prusak, L (1998) The eleven deadliest sins of knowledge management. *"California Management Review"*, **40**(3), 265–276.

Finerty, L (1997) Information retrieval for intranets: the case for knowledge management. *"Document World"*, **2**(5), 2–34.

Gal, U, Lyytinen, K, and Yoo, Y (2008) 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**(3), 290-304.

Ho, S.-P, Tserng, H.-P. and Jan, S-H (2013) Enhancing Knowledge Sharing Management Using BIM Technology in Construction. *"The Scientific World Journal"*.

Josephson, P.E. and Hammarlund, Y (1999) The causes and costs of defects in construction: a study of seven building projects. *"Automation in Construction"*, **8**(6), 681-687.

Motawa, I and Almarshad, A (2013) A knowledge-based BIM system for building maintenance. *“Automation in Construction”*, **29**, 173-18.

Neff, G, Fiore-Silfvast, B, Dossick, C S (2010) A case study of the failure of digital communication to cross knowledge boundaries in virtual construction. *“Information, Communication and Society”*, **13**(4), 556-573.

Nonaka, I (1994) A dynamic theory of organizational knowledge creation. *“Organization Science”*, **5**(1), 14–37.

Nonaka, I and Takeuchi, H (1995) The knowledge-creating company: How Japanese companies create the dynamics of innovation. New York: Oxford University Press.

Normark, M and Randall, D (2005) Local expertise at an emergency call centre. Proceedings of the Ninth European Conference on Computer-Supported Cooperative Work, 347–366.

Pavitt, K (1984) Sectoral patterns of technical change: towards a taxonomy and a theory. *“Research Policy”*, **13**(6), 343–373.

Pipek, V, Wulf,, V and Johri, A (2012) Bridging Artifacts and Actors: Expertise Sharing in Organizational Ecosystems. *“Computer Supported Cooperative Work”*, **21**(2–3), 261–282

Polanyi, M (1967) *“The Tacit Dimension”*. London: Routledge and Kegan Paul.

Scarbrough, H, Swan, J, Laurent, S, Bresnen, M, Edelman, L, and Newell, S (2004) Project based learning and the role of learning boundaries. *“Organization Studies”*, **25**(9), 1579–1600.

Schindler, M and Eppler, M J (2003) Harvesting project knowledge: a review of project learning methods and success factors. *“International Journal of Project Management”*, **21**, 219 - 228.

Schwenk, C (1988) The cognitive perspective on strategic decision-making. Journal of Management Studies”, **25**(1), 41–55.

Senge, P (1990) The fifth discipline: the art and practice of the learning organization. London: Doubleday

Spender, J C (1996) Organisational knowledge, learning and memory: three concepts in search of a theory. *“Journal of Organisational Change”*, **9**(1), 63–78.

Star, S L and Griesemer, J R. (1989) Institutional ecology, ‘translations’, and boundary objects: amateurs and professionals in Berkeley’s Museum of Vertebrate Zoology, 1907–1939. *“Social Studies of Science”*,**19**(3), 387–420.

Swan, J A, Newell, S, Scarbrough, H and Hislop, D (1999) Knowledge management and innovation: networks and networking. *“Journal of Knowledge Management”*, **3**, 262–275.

Szulanski, G (1996) Exploring internal stickiness: impediments to the transfer of best practices within the firm. *“Strategic Management Journal”*, **17**(1) 27–43.

Tsoukas, H, (1996) The firm as a distributed knowledge system: a constructivist approach. *“Strategic Management Journal”*, **17**(1), 11–25.

Weick, K (1995) Sensemaking in organizations. Sage: Thousand Oaks, CA.

Whyte, J and Lobo, S (2010) Coordination and control in project-based work: digital objects and infrastructures for delivery. *“Construction Management and Economics”*, **28**(6), 557-567.