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Understanding ~~E~~effects of BIM on ~~C~~collaborative ~~D~~design and ~~C~~construction: An empirical study in China

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Abstract

In construction projects, Building Information ~~Modelling~~Modeling (BIM) influences on the common way of ~~working and~~ collaboration, including the roles of different participants. The goal of this research ~~project~~ is to explore current practices and identify the critical effects of BIM on collaborative design and construction. Through a focus group discussion and interviews with BIM related participants, we explored project professions' understandings of BIM implementation on collaborative design and construction and adopted the grounded theory to analyze the qualitative data. Eight concepts influencing the development of BIM ~~adoption and~~ collaboration are identified and classified: (1) IT capacity, (2) technology management, (3) attitude and behavior, (4) role-taking, (5) trust, (6) communication, (7) leadership, (8) learning and experience. We discussed the taxonomy of BIM effects into three dimensions: technology, people and process. Our findings provide empirical insights into the collaborative nature of BIM construction projects and highlight the importance of collaboration within project teams in BIM project delivery.

Keywords: Collaboration; BIM; Design; Construction; Grounded theory

~~1.~~1 Introduction

In Architecture, Engineering and Construction (AEC) industry, design and construction activity involves numerous organizations working together and depending on each other to provide tailored solutions for owners. Each party working with others in the project-based construction has its own specialization, work patterns, and commitments as well as individual interests, values and culture. For many years, owners, contractors and designers from different disciplines are working together in order to achieve the project goals. However, in recent years there have been some developments that have influence on the common way of working and collaboration, including the organization of construction projects and the roles of different participants, most notably the trend towards more openness between project participants (Hertogh and Westerveld, 2010) and the proliferation of Building Information Modeling (BIM) (Bryde et al., 2013).

What we call "Building Information Modeling" nowadays was already presented by Van Nederveen and Tolman ~~in~~ (1992) though the original BIM concept can date back to 1970s (Eastman et al., 2011). The concept still remains relatively new for the industry, but attracts more attention and can achieve great improvement (McGraw-Hill Construction, 2014).

BIM can be described as a socio-technical system (Sackey et al., 2014), because it is made up both of technical dimensions, e.g. 3D modeling, and dimensions with social impact, e.g. process reengineering. The BIM trend has led to changes in the way designers and contractors work and collaborate, such as the way information is shared.

Despite these trends, it seems that the organization and roles of design and construction teams often do not change significantly. There are only ~~a~~ few examples in which it was tried to use a radically different approach such as Integrated Project Delivery (IPD) (Kent and Becerik-Gerber, 2010). In these projects, key participants form a partnership from the beginning of the project and contractual boundaries are eliminated.

Proper collaborative design and construction activities enable the information transfer, knowledge creation, technological coordination and resource allocation to operate effectively and reduce unnecessary conflicts. Grilo and Jardim-Goncalves (2010) argued that technical interoperability is not the problem for construction projects in implementing BIM, which has been shown to be feasible. Rather, the challenge is to understand and determine the value of the business interoperability, expanding the definition of collaboration.

The purpose of this paper is to explore the implication of BIM through a socio-technical systems perspective, with a particular focus on multidisciplinary inter-organizational collaboration practices. In this paper, the focus group discussion and interviews with the principles of the grounded theory are used as the research methods. It identifies the collaborating characteristics and key concepts that influence the effects of successful collaboration in BIM construction projects.

~~2.~~2 Literature review

~~2.1.~~2.1 Characteristics of AEC collaboration

The AEC sector is a typical paradigm of a project-based industry. The new non-routine design and construction processes also accompany complex working relationships and interrelations (Bresnen et al., 2004). A set of teams from various disciplines including the owner, designer, general contractor, project manager, civil engineer, MEP (Mechanical, Engineering, Plumbing) engineer, subcontractor, material and equipment supplier and BIM coordinator are employed to deliver a project. They made inter-dependent discipline decisions and naturally form a temporary multi-organization. The individual participants will finally affect the overall progress (Benne, 2005). In addition, different individual and organizational interests, expertise, expectations, resources, and constraints feature different participants (Lau and Rowlinson, 2010). Great attentions are drawn to manage these complicated interactions between different participants. Construction management is confronted with great challenges due to its increasing complexity such as the complicated and varied relations between numerous participants (Hertogh and Westerveld, 2010).

Collaboration has been explored in organizational studies' literature from a dominantly functional perspective, with much of the research emphasizing its potential benefits and purposes (Hardy and Phillips, 1998). Many innovations can be considered unbounded within the construction's inter-organizational context (Harty, 2005). The AEC industry is well known for its interdisciplinary knowledge. The collaboration process involves sharing decision making as well as data and resources (Popp et al., 2004). Project managers receive diverse information that must be checked for the reliability of content and source. With the participants of construction projects being specialized and segmented, suboptimal and inefficient solutions will be found, because each participant usually focuses on its own interests and tries to maximize these. These phenomena make us start rethinking of the collaboration of construction projects, in which legal and informal boundaries need~~s~~ to be overcome over the life cycle of the project-based construction. As the implementation of BIM brings in new and complex activities, an important topic is the identification of collaboration~~s~~ element in BIM projects.

~~2.2.~~2.2 The impact of emerging BIM on project management for construction

There is no universally accepted definition of BIM. In this study, BIM is defined as a process rather than just as software. The essential concepts for BIM were identified in the context of project communication with BIM in this research.

BIM is used for executing tasks more efficiently and in later stages more effectively, including things that were not possible before. The BIM support for collaboration has become an inevitable need due to the fragmented nature of the design and construction environment and the large quantities of information which need to be exchanged between the various participants (Isikdag and Underwood, 2010). It means that in design and construction, organizations depend on information technology to execute their specific well-defined tasks to make construction projects possible.

Therefore, the process of BIM implementation should focus on balancing these social and technical subsystems within a project in order to ensure joint optimization of both subsystems. In particular, the AEC sector is highly collaborative and requires collaboration ~~amongst~~among multiple parties.

Discussions on BIM often include arguments for collaboration across organizational boundaries. Some argue that new technologies (and BIM in particular) offer an opportunity to the paradigm shift of construction work practices (CURT, 2005) while others suggest that successful adoption of BIM requires the technologies' changes to adapt to the current work of team members (Hartmann, 2008).

However, Hartmann et al. (2008) found that most of the projects have applied 3D/4D models for only one application area in one project phase through 26 case studies in major construction projects and the majority is in the design phase. Similarly, the findings of a survey conducted by Howard and Björk (2008) indicated that BIM solutions seem so complex that they may need to be initially applied in limited areas. The coordination is limited to visualization and clash detection (Shafiq et al., 2013). Researchers contend that designers and contractors are adopting BIM tools slowly when compared to the earlier adoption of 2D CAD (Whyte et al., 2002). Important reason~~s~~ for this is that BIM projects are often tightly coupled technologically, but divided organizationally ~~(Carrie et al., 2010)~~. This means that BIM is not fostering closer collaboration across different organizations though it makes connections among project members visible (Dossick and Neff, 2009).

Collaborative design and construction build upon two recent trends in the AEC industry that have seen the widespread adoption of technologies such as BIM and innovative processes such as IPD. However, these innovations are seen to develop in isolation, with little consideration of the overarching interactions between people, process, and technology. Although BIM can be used without collaboration, such use only deal with a small part of superficial problems (Ashcraft, 2008). The interactions within as well as between parties and with their broader environmental networks make the solutions and the way of implementation of these interactions (including boundary issues) in these innovations extremely challenging.

Researchers have examined BIM from considerable technological perspectives. Many of these studies focus on examining and enhancing the interoperability of BIM technologies across project networks. When technological change spans multi-organizational boundaries in project networks, multi-organizational business practices must also evolve and adapt to these changes. How inter-organizational practices evolve when technological changes like BIM span organizational boundaries in project networks that must complement technological interoperability has been largely ignored (Taylor et al., 2009). There is still a shortcoming in the literature regarding identifying in greater depth how BIM influences collaboration development in a project setting. More in-depth qualitative approaches are needed to explore the complexity of collaboration in BIM projects.

3.3 Research Mmethodology

To the present, BIM is not competent in fostering effective collaboration in design and construction though it makes a great contribution to specific tasks in a project and builds closer connections among project participants in short- term technologically. BIM research needs to pay more attention to the people, process and their overarching interaction with technology. To provide more reliable results, the grounded theory qualitative research method is adopted in this research. In order to come up with valid factors influencing collaboration, the research will combine the use of the focus group discussion and interviews to collect data on collaboration issues in BIM projects. It is designed to probe their perceptions, attitudes and experiences relating to the collaboration when implementing BIM in projects.

Grounded theory, initially established by Glaser and Strauss (1967), is an approach focusing on generating theory based on empirical research. We chose it because it is valid when little is known about the research topic and the topic seems complex (Strauss and Corbin, 1990). The defining characteristics of the grounded theory methodology are that immediately each code is collected it isand compared with previous codes looking for similarities and connections. The main research strategy and measures for our research process are shown in Figfigure. 1.

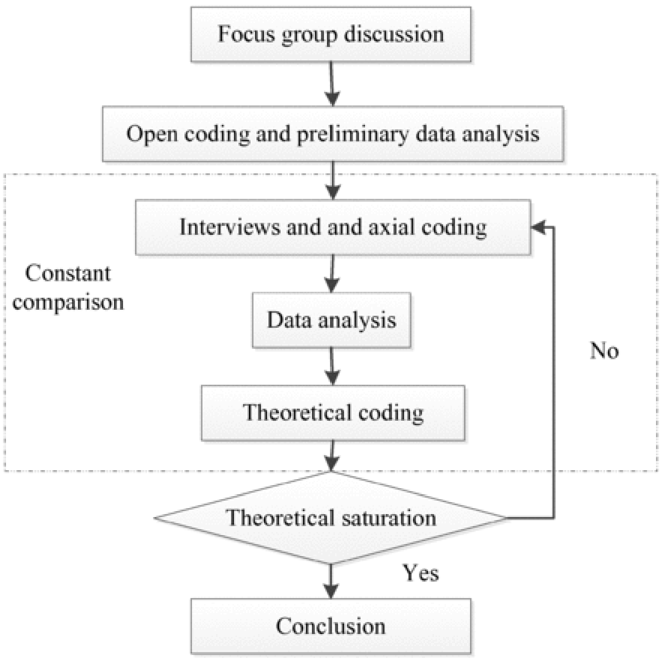


Figure 1.Fig. 1 The process of grounded theory.

alt-text: Fig. 1

The data was collected over a period of six months in 2015. We did not select firms that were using a specific BIM tool introduced into the AEC marketplace in the past decade but did require that the tool is a parametric, object-based 3D CAD tool which is the fundamental requirement of BIM spirit. We were more interested in identifying consistent paradigmatic trends across different BIM tools. The data was collected by using the following steps:

Step 1: select respondents' sources

Experienced BIM users were selected for focus group discussions and interviews, with the aim of obtaining a comprehensive understanding of the effect of collaboration. The study grouped BIM users into three types as owners, designers and contractors. The focus group discussion was arranged in an industry interest group salon involving 11 representatives from leading companies. Members of the focus group are all BIM fanciers. Of the respondents investigated, 2 come from owner firms, 7 come from design and consultant firms, and 3 come from construction firms, all of whom are located in China.

Step 2: perform the focus group discussion and open coding

According to Strauss and Corbin (1990), we do not begin the research with a preconceived theory in mind. We have opted to start on a grounded basis for a focus group discussion in China. The focus group discussion allowed the respondents to share their experiences and opinions without constrained alternatives. The purpose of focus group discussion in the former step is to stimulate ideas as many as possible. The concern on collaboration was used to facilitate keeping the discussion in focus.

We labeled relevant actions, activities, opinions and processes, which ~~is~~are called coding. Open coding was performed to extract important or repeated concepts. There were multiple key codes that emerged from the first focus group discussion. Each code that is collected is compared with previous codes looking for similarities and connections. The emergent codes and concepts that emerged from the first focus group discussion were used as a basis for the next and subsequent interview data analysis as well as keeping an open mind in the next interviews so that more codes and concepts emerged.

Step 3: perform interviews and axial coding

In addition, we organized an interview survey with 12 respondents. Details about the respondents are given in Appendix I. There was no overlap in the membership of the two methods. We used a semi-structured interview with the general questions for every interview and optional probing questions for stimulating rich descriptions. A brief description of results in the last step was given to ensure that all the respondents are informed of the same definition of each concept. Respondents were encouraged to propose additional concepts which were not mentioned in the focus group discussion according to their background and experience. Respondents represented various roles within their projects and expressed their views on the existing collaboration practices and their perception of future requirements for BIM collaboration. Events, opinions and interactions that were found to be conceptually similar in the characteristics or related in meaning were grouped under more abstract concepts. We identified each open code~~s~~ to focus on the core phenomenon, which we called the axial coding. The step stopped until survey participants underpinned that additional attention for this topic was needed which is called theoretical saturation.

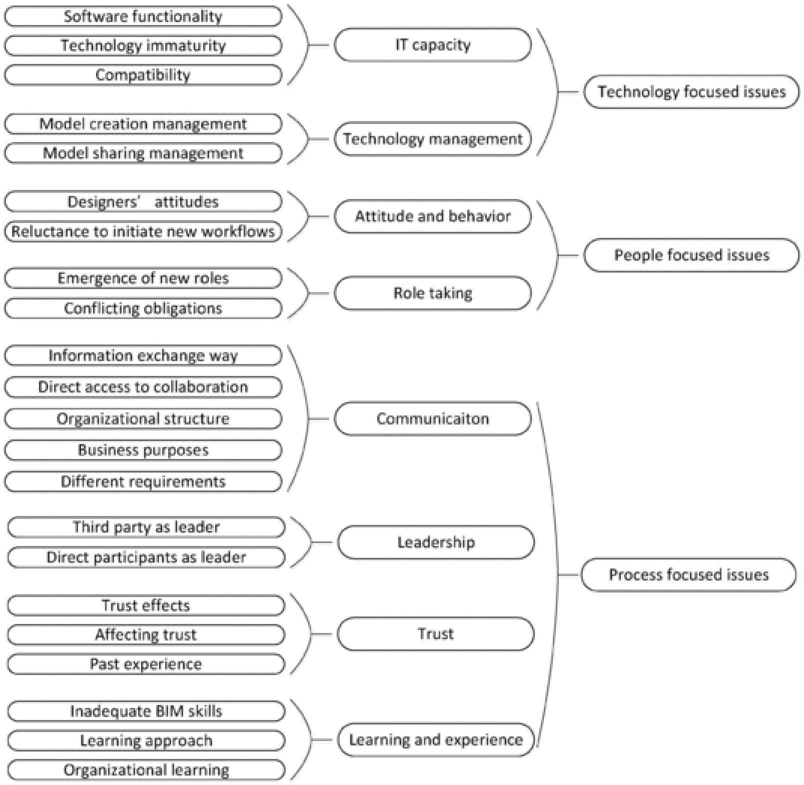
To reduce systematic bias, we guaranteed anonymity to the respondents. In addition, the process of respondent validation was used to address the validity~~-~~ of the study. The interviewees were asked to check each of codes in this step for clarity and to ensure the significance. This reduced the number of errors of facts and interpretations.

Step 4: perform theoretical coding

Reflecting on the concepts it becomes clear that some of them share common characteristics and can be grouped in higher level groups called categories. This step was used to group concepts into these categories. The concepts and categories are then theorized and cross-referenced with literature during theoretical coding. We collected interview data to saturate the concepts and categories. In the first focus group discussion, 16 codes were generated, which were classified into 8 concepts. In the interviews, ~~a~~ further 4 codes were identified, and in the last of these initial explorations,~~ a~~ further 2 were generated. Connections between the categories were explored then. The categories and connections are the main results of the study. The results of this stage of coding are a theoretical model. From these data, we developed a grounded understanding of BIM collaboration effects.

~~4.~~4 Results ~~A~~analyses

The focus group discussion and interviews revealed insights about respondents' perceptions and experiences with collaboration in BIM projects. In the study, twenty-two codes were taken from the focus group discussion and interviews. These codes were grouped together and eight concepts emerged: (1) IT capacity, (2) technology management, (3) attitude and behavior, (4) role-taking, (5) trust, (6) communication, (7) leadership, (8) learning and experience. They were classified into technology, people and process categories. These codes, concepts and categories are shown in Fig~~ure~~. 2. In this section, these eight concepts along with their corresponding codes will be examined using an inductive research approach.



~~Figure 2.~~Fig. 2 Codes, concepts and categories of BIM-collaboration effects.

alt-text: Fig. 2

~~4.1.~~4.1 IT capacity

The use of 3D BIM models for visualization and clash detection was found to lead to significant improvements (Azhar, 2011), which was also confirmed by most respondents. The interview also proved that BIM's applications in China's projects concentrate on visualization and clash detection, scheduling and quantity takeoff rather than on expert functionalities attached to BIM, such as job site safety and risk scenario planning.

IT capacity is concerned with the quality of BIM to meet current projects' requirements. Regarding collaboration, three codes were grouped in this concept and a number of respondents came up with several negative examples.

1. *Software functionality*. Despite the software vendor's claim of availability of wonderful functions, the usability of a new advanced feature is subject to how users define and implement it in practice. It is hard for the old users to be aware of existing BIM systems in terms of their potential and applications. There is no certainty that the new particular technology will bring the promised profits. We conclude that BIM tools will need to provide the increased capability for in-depth communication, rather than for just information exchange, aggregation, and storage.
2. *Technology immaturity*. BIM is not satisfactory suited in some disciplines due to its lack of capability to perform a specific task. When the participants in a design process make decisions and negotiate with one another, they use their own representations, knowledge and methods. Different driplines of designers require diverse levels of representations from only schematic representations to texture and color information without necessarily high dimensional accuracy. Many communication problems are caused by insufficiently communicated design information resulting in incorrect model interpretation. Apparently, receivers may find it hard to understand and make good use of building information models provided by their senders because they adopt different tools and standards resulting in different model formats and level of details (LOD). Performance ambiguity occurs when it is hard for a player to evaluate the outcomes or products received from another party.
3. C*ompatibility*. Interesting was the conclusion that in some situations, traditional ways can have more effective outcomes. A respondent from a design company mentioned sketching in this case. In general, BIM may not be meant to sketch, but we found that sketching by hand was an important way to communicate during meetings. In the words of the respondent, there is just a lot of subtle information in sketching and it may be lost when the information is abstracted from digital models.

Functions of BIM are limited in our daily projects and current BIM technology cannot fit in some domain of design and construction activities, which means we do not use all BIM functionalities. This is not because of unsolved technical problems but because of the incongruity between technical and social systems.

~~4.2.~~4.2 Technology management

Human-to-human and human-to-computer interactions occur during the project management process. The latter is more efficient than the former one. As the degree of project complexity rises, it gets harder to ensure the adequacy of the information flow through human-to-human communication (Cerovsek, 2011). One of the BIM usage purposes is that models can replace some human-to-human communication by human-to-computer. Traditional construction practices require the same information to be used multiple times by multiple organizations. BIM models solidify the information in a digital file which is the core of BIM. With the ability to exploit and reuse information directly from the models, the current interdisciplinary collaboration can evolve towards integrated multi-disciplinary collaboration on models (Singh et al., 2011). If these models are properly maintained during construction, they can become tools that can be used by the owner to manage and operate the asset more effectively and efficiently.

~~4.2.1.~~4.2.1 Model creation management

This code consists of model content creating, viewing, sharing, administrating and storing. Thus, participants in the industry can act as the contributor, user, and coordinator of the model content. Respondents agreed that the most significant difference compared with traditional ways lies in the emergence of the model creation. Model content creation is largely a local operation which may not depend on the collaboration before the model content is published. A BIM model can be created and maintained in-house or outsourced to the third party consultants. These two ways were both reported to be adopted by respondents.

~~4.2.2.~~4.2.2 Model sharing management

Collaboration is needed when the model is ready around the viewing, sharing, administrating and storing domain, mainly because of the growing need for model sharing with participants and increasing BIM obligations. There are different ways to create models and these will result in specific requirements for collaboration. For instance, when the model is established in-house, the designer and contractor can freely abstract information from it. But when the model creation is outsourced, it is hard to form a collaborative environment. One respondent gave an example when they outsourced the model creation to a large-scale state-owned architectural design and consulting institute. The institute did not share files with other parties on projects. Additional model use services were charged every time.

The implementation of BIM leads to the birth of management for model creation and sharing (we call it technology management here). The industry is busy with adapting BIM content creating, viewing, sharing, administrating and storing, but pays less attention to the management of above functions.

~~4.3.~~4.3 Attitude and behavior

A frequently discussed issue in the focus group discussion and interviews was the asymmetrical rewards of BIM between organizations. This seems to be a significant practical obstacle from the perspective of the designers, who are the linchpins of BIM. This also requires a visible change in the existing workflows.

~~4.3.1.~~4.3.1 Designers' attitudes

Design firms are expected to pay more attention in the practice of their profession. They must install the software, upgrade the hardware, train their employees, and up-skill the BIM use. They need to restructure their workflows and reinvent the design process. If they do not share the economic benefits, designers will have little incentive to adopt BIM processes. In fact, because BIM can increase the designer's potential liability, there is a significant disincentive to adopt BIM. From the designer's point of view, there is a reluctance to pay for additional hardware and software cost, not to mention the reluctance to invest as much time in design complicated 3D models as required. For designers, however, BIM's economic benefits are less apparent. The difficulty in characterizing and insuring against this type of loss underscores the necessity of comprehensive risk allocation and waivers among all model users. Unless the designers share the economic benefits, the owner, not the designer, reaps the immediate rewards. Yet it is the designer, not the owner, who must adopt BIM and make the investment. When the contract requires the use of BIM but the additional bonus is not supplemented, designers will certainly have a strong negative emotion.

~~4.3.2.~~4.3.2 Reluctance to initiate new workflows

There is a reluctance for designers and contractors due to economic benefit~~s~~ distribution. The owner is looking for a return on investment quite instantly. The use of BIM should be accompanied with increasing collaborative working for shared benefit following the information flow from the design to the contractor. Then every party can harvest their deserved profits.

~~4.4.~~4.4 Role taking

The respondents claimed that the roles and responsibilities of individual participants are not likely to fundamentally change when BIM is implemented. This is confirmed by Smith and Tardif (2009). Respondents stressed that new roles and relationships within the project teams are emerging. These include BIM specialists and BIM modelers in the BIM departments many companies have started to set up. The drawing and modeling in a BIM project increase the size of the staff. This is also found in the literature that trained people are scarce (Aranda-Mena et al., 2009) and existing personnel often have to be trained to use a particular technology (Li et al., 2011).

~~4.4.1.~~4.4.1 *Emergence of new roles*

The BIM modeler and coordinator emerged. They have won a position in participating the design and construction activities. Modelers can assign tasks and rights for the model elements, send and receive model data. This is in agreement with the earlier study that teamwork features in current BIM tools enable coordination of modeling work and allow basic communication within BIM tools (Cerovšek et al., 2010). For a modeler, the modeling in a design can be either internal or external (Kalay, 2004). The modeling work is internal when designers seek individual reflection. The modeling work is external when representations must be communicated between project participants. These two types of work are playing a more important role.

~~4.4.2.~~4.4.2 *Conflicting obligations*

A number of respondents state that the role of the modeler was difficult. They have to collect the information under complicated circumstances, do extensive modeling often starting from the 2D contractual documents, and then notify designers and subcontractors for potential clashes, often faced with a response that such clashes would be found on-site anyway (Allen et al., 2005). Moreover, each modeler has a specific scope of work, but their work often relies upon the decisions and designs of others. However, current legal framework assumes a less collaborative environment with a clearer definition of responsibility. Respondents often mentioned contractual issues as barriers to achieving integrated teams. Legal and contractual obligations often restrict potential collaboration with other parties. Respondents suggested that specifying ownership, updating liabilities and clearly defined responsibilities of project participants would need careful consideration. The full potential of BIM and collaboration cannot be realized without corresponding changes in the work tasks and skill sets of the project participants.

Because of BIM, new roles, especially the BIM modeler and-_coordinator, are introduced into the project process. They act as a role to improve the information quality and facilitate better communication. However, their full advantages are restricted in the current construction context due to unaddressed obligation issues.

~~4.5.~~4.5 Trust

The success of a project depends on the projects team members to integrate the relevant knowledge, expertise, and skills. When they work together, trust was found to be crucial according to the respondents. This is in line with literature where trust is an important part of inter-organizational relationships (Kumar et al., 1995; Doney and Cannon, 1997).

~~4.5.1.~~4.5.1 *Trust effects*

In a BIM project, various parties lack prior collaboration and experience based on BIM implementation. This often leads to difficulties to trust each other in the beginning. Respondents came up with several reasons such as liability concerns, quality concerns unauthorized reuse of intellectual property why the designer doesn't want to share BIM with contractors. On the other hand, many contractors are unwilling to acquire BIM models from designers due to the lack of confidence in the design models, uncertainness of ownership or copyright and- extra time spent reviewing models. Subjectively, in order to put the BIM theory, which is relatively new for all, into practice, personnel from different parties must sit together and hold more formal meetings and informal discussion than traditional ways. Respondents shared the experience that BIM calls for more frequent interaction with team members. It is more likely to strengthen relationships among the team members and result in a higher trustworthy environment. This insight was also found in the literature (Webber, 2008).

~~4.5.2.~~4.5.2 *Affecting trust*

Collaboration between designers and contractors affects not only operational outcomes but also affect trust relational outcomes. When designers and contractors collaborate intensely in the environment of BIM, they openly share information that allows their partner to better understand their expectations, predict their actions and demonstrate a desire to help. Public models among all the parties demonstrate a commitment to each other that nurtures an atmosphere of trust. As a result, the trust between different parties is enhanced. This is in line with the findings of Laan et al. (2011) that both prior experiences and prospects of future exchange influence trust between partners in the construction industry.

~~4.5.3.~~4.5.3 *Past experience*

When team members have never worked with each other as a team, the experience of the respondents is that they need to spend a great amount of time in getting acquainted with each other and clarify their mutual roles and expectations. The experience and history of designers and contractors with their collaborators influence the formation, performance and as a result the success of new collaborations. Designers and contractors can learn from previous collaborations and develop collaborative strategies to form a partnership. However, the influence of prior experience will vanish as the new collaborating elements emerge and trust relationships are changed (Zollo and Winter, 1999). Furthermore, past non-BIM experience will only lead to the success of the old type but will not necessarily contribute to the type of collaboration in the new context of BIM. Similar experiences of BIM have a positive effect on winning a tender. The BIM history enables the implementation of BIM with others and increases its positive impact.

Views from respondents revealed that a deeper trust relationship plays a vital role in inter-organizational collaboration and the performance of collaboration and communication through BIM, in turn, has a positive influence on the conformation of trust.

~~4.6.~~4.6 Communication

BIM can foster an open communication environment but the construction project separation between design and construction teams, in turn, hinders the direct communication.

~~4.6.1.~~4.6.1 Information exchange way

Traditionally, the way data is transferred in isolated files via blueprints, work reports and minutes of periodic meetings was linear. There are lots of possibilities for coordination to be missed in this process, especially with specialists with different disciplines, who often do not think about the other disciplines' responsibilities. Implementing BIM changes the way of information exchange. In practice, more people tend to sue BIM models to exchange information and try to integrate much more details from scratch. This enhances the scope of BIM usage in a project from a tool to a collaboration platform.

~~4.6.2.~~4.6.2 Direct access to collaboration

In the project, there are various levels of roles, some of whom may not have direct access to the BIM models for various reasons. It is in this way that modelers cannot receive enough feedbacks and have little tangible influence over the project. Thus, they feel constrained by project decisions in which they had no voice, as was stated by the respondents. While they may have the ability about how to resolve conflicts or small design changes, downstream model users are blocked from these potential ideas and solutions.

~~4.6.3.~~4.6.3 Organizational structure

For inter-organizational communication, the organizational structure of a construction project typically separates design and construction teams. The designer may be reluctant to share their models due to liability concerns, unauthorized intellectual properties reuse, and misinterpretation risks of the information. In traditional contracts, the contractor does not have any impact during the design phase, thus, the contractor's knowledge of material availability, constructability, value engineering and so forth in a very limited way can be incorporated into the project execution. Modelers that are depended on the general contractor's coordinator to communicate disciplinary issues to the other contractors and designers cannot communicate directly with design and construction teams to navigate and to get information from them and back to the team. Modelers are forced to rely on formal communication channels and have no confidence in the digital information that they have. Modelers may be experts at modeling, but they don't have knowledge about construction. Their task mainly focuses on clash detection and the number of clashes is inappropriately regarded by the client as saving a lot of money. As a third party, modelers have no right to modify drawings without revised drawings, the contractor cannot execute the new construction program. No one takes responsibility for the clashes so the clash detection report might not produce the effect. In this way, the collaborative process is generally still linear rather than integrated.

~~4.6.4.~~4.6.4 Business purposes

Two main types in which the contractors use BIM to communicate with other parties are the submitting of a BIM execution program in the preconstruction phase as well as conducting the clash detection in the construction phase. According to the interviews, neither is aimed at improving the communication between actors. The former usage is required by the owner to prove their technical expertise while the later one is to test the design document and BIM itself implying they do not believe in BIM for deep communication. These functions of BIM usage are more adopted for commercial propaganda and negotiation with clients.

~~4.6.5.~~4.6.5 Different requirements

For design disciplines, BIM is an extension to CAD in the way that plans and construction drawings are created, whereas, for non-design disciplines such as contractors and project managers, BIM is more like an intelligent management system that can quickly take off information from 3D models directly. There are evident overlaps, individual BIM software cannot allow the flexibility that different actors require.

~~4.7.~~4.7 Leadership

Leadership was an issue that many respondents mentioned as important for collaboration and effectively working together by doing more than simply acquire knowledge from the other firm and apply it. The industry has definitely a need for leaders who can bring the team together and complete the work collaboratively, rather than solely face the challenges of restructuring projects organizationally to support collaborative work.

The ideal open and free information exchange is limited in the unidirectional information flow. When design errors are found in the clash detection, or the unreasonable construction schedule is discovered in the visualization roam, in practice the problems are hard to be corrected in inter-organization because the designer and contractor have no authority over the other. The problem of organizational separation was already mentioned in the former sub-section to cause ineffective communication. The participants blamed the owner coordinator for a lack of leadership when communication through the project hierarchy broke down.

~~4.7.1.~~4.7.1 Third party as leader

Special professions would encourage closer collaboration among project team members. Although naturally emerging leadership is more effective than assigned leadership, some owners introduce the role of BIM consultants in their project management because they think that parties with BIM execution capability are scarce. The benefit of BIM can be achieved only under the leadership of a certain party (so far the owner chooses the third party) ~~in~~and a unified working pattern is the idea.

~~4.7.2.~~4.7.2 *Direct participants as leader*

The third party for leading the BIM implementation is strongly disagreed by designers and contractors. Respondents from these roles stated that anyone who can contribute to a positive group climate was emphasized to be a key leader for productivity and creativity. Take the designer as an example. The work of designers is finished after handing over the design document and models to the owner. The designers lose control over their ideas and how they were presented. It is not possible for the designers to influence how their suggestions are presented in BIM tools when they do not connect with contractors for continuous improvement of design processes and constructed facilities. When they are delegated as the leader for implementing BIM, this allowed the designers to have more control over the models. As the models come from the original ideas of designers, their profession can remove much technical uncertainty in the following BIM use.

The emergence of BIM changes the collaborators per task and intensity of collaboration. Therefore, leadership is needed for coordinating between different participants. A third party such as the consultant outside the direct participants is often chosen to realize this aim but other participants like the designer and contractor also have the potential to act as the leader role in particular settings and in general these parties are not in favor of a third party consultant.

~~4.8.~~4.8 Learning and experience

Respondents in the study come from three types of AEC parties: owner, designer/consultant and contractor. In traditional contracting, the owner buys the intelligent outcome from the designer/consultant and transfers it to the contractor. Then the contractor puts it into practice. As the technology develops, practices and functions of the people using the technology change too. The most significant change induced by BIM on knowledge is that BIM facilitates and accelerates the transfer rate between the knowledge and experience.

~~4.8.1.~~4.8.1 *Inadequate BIM skills*

Respondents stated that almost everyone related to BIM must take part in the BIM training while in practice, most of the personnel participating in the training are young staff with insufficient experience. This trend might result in the trend that a young staff member with little experience can be skilled with BIM tools while a very experienced veteran has to rely on him to operate BIM functions due to his lack of skills of BIM software.

~~4.8.2.~~4.8.2 *Learning approach*

The findings from the interviews discovered the inexperience of end users and their variations in preferred solutions between owners, designers, and contractors, as was also mentioned in the industry report (McGraw-Hill Construction, 2008). Owners outsource BIM completely, and therefore, they seldom need particular training. While in the design institute, senior designers are more likely to have courses by external trainers and new employees are recruited with a requirement of the good master of BIM skills. Contractors teach themselves because they take over models from designers.

~~4.8.3.~~4.8.3 *Organizational learning*

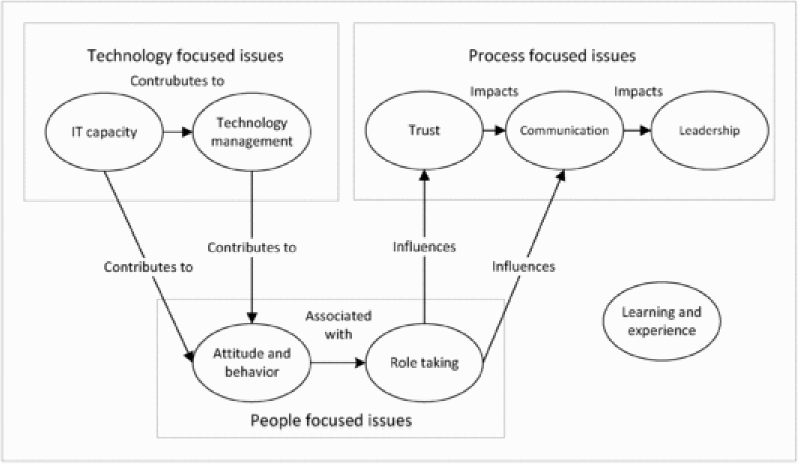
This code has been identified to facilitate continuous improvement of team members and enable the team to remain competitive. To build a learning organization, particularly for designers and contractors, it is necessary to stimulate the learning and innovation culture (Kululanga et al., 2001). However, in design and construction organizations investigated in the research, there is little interest in learning from projects at completion stage or passing on knowledge to new projects. As was already concluded in ~~2003 (~~Love et al. (2003)~~)~~, but more than ten years later it was mentioned that this still the case. Most of the respondents are a strong proponent of the idea that BIM offers a perfect opportunity for the whole industry to implement change and enhance better collaboration. In general, employees must be prepared to change and make adjustments on their skills which will contribute to the organization.

BIM facilitates and accelerates the transfer rate between knowledge and experience. Organizational learning has been pinpointed as the best way for delivering continuous transform in collaborative BIM processes.

~~5.~~5 Discussion and ~~I~~implication

BIM has been implemented in the different stages of construction and different organizational levels to facilitate collaborative work. Successful collaboration in any context requires the successful execution of and dedication to three main components: technology, people and process, which are also three categories classified based on the above investigations. These three components are complementary and synergistic. Any of these components can be implemented independently, but will have less effect on successful project collaboration if done in the absence of its complementary components.

These factors are not independent. A model of BIM-collaboration effects is developed here to provide practical insight into the BIM collaboration effects. These effects and their relationship are illustrated in Fig~~ure~~. 3 below.



~~Figure 3.~~Fig. 3 Model of BIM-collaboration effects.

alt-text: Fig. 3

In this model, eight concepts drawn from the focus group discussion and interviews are classified into four categories as technology focused issues, people focused issues, process focused issues and growth focused issues. The figure is explained below.

~~5.1.~~5.1 Changing and emerging roles in collaborative design and construction

The vision of BIM is that all parties in the project collaborate based on the same source of information, and make better decisions with improved reactions of others, allowing participants to define and communicate their requirements better, diminish rework on site, and remove unnecessary waste in the process. These phenomena were mentioned in the focus group discussion and interviews and make us think that BIM adoption implies on several changes in the way project management processes and human–technology interactions are structured and developed.

In terms of technology focused issues, the effects are related to IT capacity and technology management. It is taken for granted that BIM technology is not good enough at present. BIM as a tool cannot be directly used by everyone in daily work. The specific technology management stems from the current IT capacity of BIM. Both the two technology focused issues contribute to people focused issues involving changing collaborative behavior and consciousness of different participants.

Project managers are often very skilled and knowledgeable about the construction practices. However, since they are used to working with 2D drawings and information on paper, they are not equal to younger staff in IT experience and capacity. Moreover, project managers have to be in control in their role in order to effectively run construction projects, and if given the wrong tools or tools they cannot understand well, they can feel that they lose control. An emerging participant is the BIM coordinator, who acts as a supporting role for the project manager and is responsible for technical issues regarding BIM, and could fulfill a role in this.

Multiple actors in the project participating in conducting BIM perform managerial tasks and take roles. Team members need to change current work practice via appropriate training and modifying role taking in order to be able to contribute and participate in the new type of collaboration. In general, dedicated roles, such as BIM coordinator whether as a third party or from design and construction firms will be inevitable. The BIM coordinator is in a unique position to judge the processes for managing the project.

From our research, it is notable that two of those roles – the controlling role and the supporting role – showed a significant and positive impact on the collaborative performance of project management. The project manager is responsible for the physical construction (the controlling role), for which the BIM coordinator can support by facilitating the virtual construction and assist the team before and in the construction (the supporting role). The project manager as the controlling role strives to establish and maintain a sound information resource, thus increasing the high quality of communication. The BIM coordinator as the supporting role facilitates project management, improves information transfer between projects and stimulates communication. Activities of the controlling role are proposed to positively impact on information quality. In contrast, a lack of communication limits opportunities for collaboration because information on accurate facts and alternative directions is missing. Project participants can benefit immensely from this process as their ability to inform the design early on is greatly enhanced.

~~5.2.~~5.2 Collaboration process in BIM projects in the vertical perspective

Organizations involved in the design and construction of buildings and infrastructure are being impacted by the BIM. In theory, all collaborators communicate with each other through BIM. However, at present, it is not the case, because not all parties are involved sufficiently. In looking at process focused issues, it is useful to focus and highlight the change between traditional and BIM processes.

The initial step of BIM focuses on the incentives for organizational collaboration, removal of technical and personnel problems. With decades of development, there is a number of advanced service in the BIM market. Designers and contractors can select the proper software and hardware according to anticipated business needs. Collaboration patterns in traditional and BIM projects are similar in the mobility stage. However, actions, training, and responsibilities vary for each partner in the project management process.

During the collaboration, designers and contractors need to choose the collaboration type to communicate with each other, establish trust relationships, and increase collaboration performance and the final success rate. Through the focus group discussion and interviews, several significant aspects are clustered such as trust, communication and leadership.

There are differences in the collaboration capability in traditional and BIM projects at different stages of the project management process. The introduction of BIM forced the industry to learn new technology and the way of collaboration at a fast speed. However, the total level of collaboration still remains inadequate to reach the benefits of working in a BIM environment. Single firms can improve its strength by learning, which is beneficial, but most added value of BIM technologies will be supporting other organizations during the project management process. A number of designers and contractors compete in the BIM market by self-promotion. However, if participants in the BIM projects cannot be connected closely, larger achievement cannot be obtained.

In the end, each design and construction firm involved is expected to get tangible or intangible benefits and accumulate experience and knowledge, which will be used in the next round of collaboration with the same or other partners. We summarized it as Trust which can then impact Leadership between all parties in the long term.

The current collaboration process described in Communication shows what is called “Jevons Paradox”. It is a term describing in economics when technological progress increases the efficiency with consuming resources, but the rate of resource consumption rises because of increasing demand. At a superficial level, by using BIM, designers spend less time drafting and more time designing resulting in better design quality, and much time once used for understanding design purpose and arranging construction schedule is saved. It is evident that consequence is often the additional time and resources needed to model the required information. Each organization incurs a new cost for participating (i.e. costs of purchasing BIM software licenses), for which they may not be compensated. This forces them to trade off in a different way and take resources from other activities. Respondents all agreed that the BIM saves resources for society but it is not guaranteed to see benefits for the participating organizations.

~~5.3.~~5.3 Collaboration process in BIM projects in the horizontal perspective

New types of collaboration will be facilitated by new technological advances. In today's project delivery practice though using BIM, traditional contractual agreements like Design-Bid-Build (DBB) is a most common way to deliver a project. These are based on the waterfall model. BIM by means of Concurrent Engineering (CE) has adopted the concept of iterative and collaborative processes. It was found from respondents that collaborative delivery methods such as IPD and Design-Build (DB) are more appropriate for BIM-based projects. They have practices related to the use of BIM-based project delivery.

The respondents suggested that the relationships among involved participants are required to move towards more partnering-like relationships for effective implementation of BIM. Participants would be involved earlier in the project process to provide insights concerning their particular competence, of which the contractor is an important example. This may lead to more predictability of project scope, schedule, and costs, which will lead to higher communication quality and reduce the residual performance risk, which increases performance as was already promised twenty years ago (Nidumolu, 1996).

As a new form of project delivery, IPD gained popularity together with BIM. IPD aims to take the integration which many designers and contractors have practiced into a trustful and communicative level in which IPD promotes the concept that by sharing the risk and reward of a project through common target project goals. It is a project delivery form that suits BIM for construction projects very well. However, we are aware of the fact that there is no clear and uniform approach established which is necessarily feasible or desirable (Hassan Ibrahim, 2013).

The grounded analysis indicates that past experience, especially BIM adoption history may facilitate the early establishment of working practices significantly as well as trust development in the project team (Buvik and Rolfsen, 2015). The presence of positive trust and communication from the beginning can serve as an integrating mechanism and facilitate coordination and leadership of the project team members. Project partners are increasingly getting involved in the early stages, helping to develop and plan the construction projects through BIM tools optimizing the efficiency of the construction execution program in a collaborative environment. Moreover, prior to the commencement of construction, the project scope of the project and the roles and responsibilities of the project participants also need to be defined and established more clearly.

Partnering is a collaboration form which addresses the possible benefits of BIM. It focuses on close relationships between participants with mutual trust and openness. Emphasi~~ze~~s is on best value rather than just lowest cost. Specific to the construction projects, partnering will occur between the design and construction entity. In current more traditional practices, the designer mainly leads the BIM adoption. It is important for the design team to present their work to the construction team by virtual models that are understandable and comprehensive for contractors. A contractor's knowledge and experience ~~is~~are more valued and utilized in a technology applied integrated process. Where does a contractor fit in a BIM process? In light of these arguments, we suggest that the owner will probably seek design-contractor delivery method and contract a single entity, which will deliver higher value. The purpose is to increase accountability and have a single source of project delivery. The design-contractor is responsible for streaming the process by combining the design and construction tasks.

~~6.~~6 Conclusions

This study aims to explore and identify multiple influential factors in the initiation and development of BIM projects and to determine which factors critically affect the project performance. The identified concepts have been examined separately for their effects and relationship with each other. The effects are mainly related to the features of BIM itself and the social context within which BIM is implemented. This is also confirmed by Linderoth (2010).

The integration of disciplines and stages in design and construction activities is a key aim of major projects and an underlying theme of integrated approaches to project delivery. However, BIM collaboration achieves only partial integration, in some stages, disciplines, or teams in the project. The application of BIM has not permeated all segments of the construction sector and they are not always used in an integrated manner crucially even in major projects.

This study found that the development of BIM should be extended to trust and communication requirements. Although BIM technologies have been presented as a solution to collaboration challenges in the industry, we find that projects with BIM face organizational challenges that limit collaboration. Managing the “soft” factors is of equal importance as the “hard” factors. Our research question addressed how BIM influences the collaboration development in multi-disciplinary project teams. We have conducted research on the interaction between technology, people and process, and its effect on adapting working practices and learning.

Based on the focus group discussion and qualitative interviews, this study identified eight concepts which contribute to the level of BIM construction projects collaboration. This implied that among factors including (1) IT capacity, (2) technology management, (3) attitude and behavior, (4) role-taking, (5) trust, (6) communication, (7) leadership, (8) learning and experience, inhibit adoption of the groupware technology. Critical concepts were identified and analyzed to achieve a general understanding of these variables.

The focus group discussion and interviews data echo some of the earlier findings that successful technology depends on many influential factors including people's attitudes and behaviors ~~toward~~towards the technology, individual's resistance to change, relationships between parties and communication density (Nitithamyong and Skibniewski, 2006; O'Brien, 2000). Technical concerns, the lack of clarity on roles, unprepared communication approach in adopting BIM in traditional organizational structure and misfit trust environment are some of the important factors inhibiting BIM adoption in practice.

The existing two party construction contractual relationships are not appropriate for regulating the multi-party collaboration. Using BIM substantially alters the relationships between parties and blends their roles and responsibilities. The adoption of BIM practices requires business process reengineering. The transition should be supported by appropriate organizational structures and a social development of competencies of people. People in the industry could be motivated with features that supporting and controlling models usage in BIM construction projects. The role of the BIM coordinator accepted by designers and contractors can be of benefit if given more emphas~~iz~~es. A better understanding of the collaboration process could lead to better BIM technologies. Innovative performance of designers and contractors in the first beginning of the life cycle can promote collaboration and will lead to expected collaborative outcomes. Based on these arguments and empirical findings, we conclude that the early involvement of design and construction parties as well as contracting with a single mutual trusted entity with a clear leader to deliver BIM construction projects can facilitate the collaboration needed.

The success of BIM depends on the collective adoption by all the participants in the collaboration activities. In the fast developing AEC industry, it is crucial to improv~~ing~~e BIM-collaboration patterns. BIM could perform like a catalyst, enabling fast and efficient collaboration among different participants. Monitoring the evolution of the relationship between BIM and project management in the upcoming years is a key to the successful BIM adoption in the sector. The findings in this study contribute ~~to~~in revealing the evolving trajectories for BIM implementation.

~~7.~~7 Future directions

Although this paper has contributed to an understanding of the critical effects of collaboration when BIM is implemented, it has also created a need for further research. It is necessary to elicit an assessment model using these critical effects based on professional opinions. This can help project managers to choose the appropriate measures to be adopted to manage the collaboration.

Countries that have used BIM have different economic, legal, and institutional environments. Therefore, this study could be expected to be a foundation for studies on collaboration for BIM in different countries.

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Appendix I. Features of respondents and their projects.

alt-text: Image 1

Respondents	Positions	Company type
Owner 1	Project manager	Real estate developer
Owner 2	BIM coordinator	Real estate developer
Designer 1	BIM coordinator	AEC technology company
Designer 2	BIM coordinator	Engineering consultancy services company
Designer 3	Architectural designer	Design and research institute
Designer 4	BIM coordinator	Management consulting company
Designer 5	Structural designer	Design and research institute
Designer 6	Structural designer	Design and research institute
Designer 7	Project manager	AEC technology company
Contractor 1	Project manager	Building work contractor
Contractor 2	Project coordinator	Construction underground space contractor
Contractor 3	Project coordinator	BIPV work contractor

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Highlights

- We undertook a grounded theory-based focus group discussion and interviews.
- Eight influential concepts of BIM on collaborative design and construction were revealed.
- The research examined closed human-technology interactions of BIM and their social context.
- Our findings contribute to the 'soft' area of BIM research.

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Query:

Please identify the corresponding author and provide the correspondence address.

Answer: Yan Liu is the corresponding author and the correspondence address is Infrastructure Design and Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN, Delft, the Netherlands. Email address: y.liu-9@tudelft.nl.

Query:

Please provide an abstract with a maximum of 150 words.

Answer: In construction projects, Building Information Modeling(BIM) influences on the common way of collaboration, including the roles of different participants. The goal of this research is to explore current practices and identify the critical effects of BIM on collaborative design and construction. Through a focus group discussion and interviews with BIM related participants, we explored project professions' understandings of BIM implementation on collaborative design and construction and adopted the grounded theory to analyze the qualitative data. Eight concepts influencing the development of BIM collaboration are identified and classified: (1) IT capacity, (2) technology management, (3) attitude and behavior, (4) role-taking, (5) trust, (6) communication, (7) leadership, (8) learning and experience. We discussed the taxonomy of BIM effects into three dimensions: technology, people and process. Our findings provide empirical insights into the collaborative nature of BIM construction projects and highlight the importance of collaboration within project teams in BIM project delivery.

Query:

Please check the hierarchy of the section headings and amend as necessary.

Answer: Yes

Query:

The citation "Lau and Rowlingson, 2010" has been changed to "Lau and Rowlinson, 2010" to match the author name/date in the reference list. Please check if the change is fine in this occurrence and modify the subsequent occurrences, if necessary.

Answer: Yes

Query:

Refs. "Howard and Björk (2008)", "Carrie et al., 2010" are cited in text but not provided in the reference list. Please provide it in the reference list or delete the citation from the text.

Answer: Howard, R. , and Björk, B. C. (2008). “Building information modelling—Expert's views on standardisation and industry deployment .” Adv. Eng. Inform. , 22 (2), 271–280. Please delete the citation "Carrie et al., 2010".

Query:

The citation "Dossick and Neft, 2009" has been changed to "Dossick and Neff, 2009" to match the author name/date in the reference list. Please check if the change is fine in this occurrence and modify the subsequent occurrences, if necessary.

Answer: Yes

Query:

Ref. "Taylor et al., 2009" is cited in text but not provided in the reference list. Please provide it in the reference list or delete the citation from the text.

Answer: Taylor, J. , and Bernstein, P. (2009). “Paradigm trajectories of building information modeling practice in project networks.” J. Manage. Eng. , 25 (2), 69–76.

Query:

The citation "Strauss et al., 1990" has been changed to "Strauss and Corbin, 1990" to match the author name/date in the reference list. Please check if the change is fine in this occurrence and modify the subsequent occurrences, if necessary.

Answer: Yes

Query:

Please check all the captured subsection titles if appropriate. Amend as necessary.

Answer: Yes

Query:

The citation "Laan et al. (2012)" has been changed to "Laan et al. (2011)" to match the author name/date in the reference list. Please check if the change is fine in this occurrence and modify the subsequent occurrences, if necessary.

Answer: Please use Laan et al. (2012) and the reference should be Laan, A., Voordijk, H., Noorderhaven, N., and Dewulf, G. (2012). "Levels of Interorganizational Trust in Construction Projects: Empirical Evidence." J. Constr. Eng. Manage.

Query:

Would you consider changing the phrase "influence the formation, performance and as a result the success of new collaborations" to "influence the formation, performance and the result for the success of new collaborations"? Please check, and amend as necessary.

Answer: Yes

Query:

This sentence has been slightly modified for clarity. Please check and confirm if the meaning is still correct.

Answer: Yes

Query:

The term "Emphasizes" has been changed to "Emphasis". Please check if this change is appropriate, and amend if necessary.

Answer: Yes

Query:

Please provide a conflict of interest statement. If there is no conflict of interest, please state that.

Answer: Conflict of interest There is no conflict of interest.

Query:

Uncited references: This section comprises references that occur in the reference list but not in the body of the text. Please position each reference in the text or, alternatively, delete it. Thank you.

Answer: Please delete Adriaanse et al., 2010 American Institute of Architects, 2008 Debra et al., 1995 Gulati, 1995 Malcolm, 2000 Mayer et al., 1995 Ring and Van de Ven, 1994 Sorenson and Waguespack, 2006 Taylor and Levitt, 2004 I have position Zollo and Winter, 1999 in the text.