https://doi.org/10.1061/(ASCE)ME.1943-5479.0000647

A Conceptual Framework and Roadmap Approach for Integrating BIM into Lifecycle Project Management

Xiaozhi Ma[1], Feng Xiong[2], Timothy O. Olawumi[3], Dong Na[4], Albert P. C. Chan[5]

Abstract: As a disruptive information and communication technology (ICT) in the architecture, engineering, construction, and operation (AECO) industry, building information modeling (BIM) enables project teams to manage a project via a model-based cooperative approach. Although it has a widespread impact on the industry, the systematic implementation of BIM in projects faces challenges. This study integrates BIM into the life cycle of a building project with the introduction of a conceptual framework constituted by BIM Information Flow, BIM Model Chain, BIM Workflow, BIM Institutional Environment and BIM-based Project Management Information System (PMIS). This conceptual framework identifies the key areas for integrating BIM into the project life cycle and explains how BIM works for project management practice. Through an ethnographic action research approach, the study develops a BIM roadmap for the project life cycle by systematically implementing BIM in the building project. The major findings and pieces of evidence derived via the implementation support the conceptual framework. The following discussions explain how BIM disrupt the project from the perspective of organization design and clarify the contributions of this study in project management as well as BIM adoption and integration. Finally, the conclusions focus on the development of this research, the role of the conceptual framework to underlie the BIM roadmap, and the research limitations. Recommendations are provided towards future research works.

Author Keywords: Project management; Project life cycle; Building information modeling (BIM); Conceptual framework; BIM-based project management (BPM); BIM roadmap.

1.Ph.D. Candidate (Joint Program), College of Architecture and Environment, Sichuan Univ., No.24 South Section 1, Yihuan Road, 610065, Chengdu, China; and Dept. of Building and Real Estate, Hong Kong Polytechnic Univ., 11 Yuk Choi Rd., Hung Hom, Kowloon, Hong Kong, China. E-mail: xiaozhi.ma@connect.polyu.hk

2.Professor, College of Architecture and Environment, Sichuan Univ., No.24 South Section 1, Yihuan Road, 610065, Chengdu, China. E-mail: fxiong@scu.edu.cn

3.Ph.D. Candidate, Dept. of Building and Real Estate, Hong Kong Polytechnic Univ., 11 Yuk Choi Rd., Hung Hom, Kowloon, Hong Kong, China. E-mail: Timothy.o.olawumi@connect.polyu.hk

4.Associate Professor, College of Architecture and Environment, Sichuan Univ., No.24 South Section 1, Yihuan Road, 610065, Chengdu, China (Corresponding author). E-mail: dongna@scu.edu.cn

5.Chair Professor, Dept. of Building and Real Estate, Faculty of Construction and Environment, Hong Kong Polytechnic Univ., Hung Hom, Kowloon, Hong Kong, China. E-mail: albert.chan@polyu.edu.hk

Introduction

Project management, which encompasses multifarious procedures, disciplines, and teams, has been widely adopted in the architecture, engineering, construction and operation (AECO) industry to organize building production. The increasing complexity and scale of projects in the industry require the integration of processes and interfaces of multidisciplinary efforts to handle constant project changes (Alshawi and Ingirige 2003; Egan 1998). The complicated task of information handling in modern project management demands constant decision makings to update plans with continuously renewed project information (Pich et al. 2002). In response to this situation, various information and communication technologies (ICTs) have been introduced to the industry to address information management issues, promote communication and collaboration, and achieve advanced practices (Ahuja et al. 2009; Lu et al. 2014). Among various ICTs, building information modeling (BIM) enables teams to manage projects via a model-based cooperative approach (Bryde et al. 2013; Froese 2010; Succar 2009).

Moreover, BIM has been widely applied in building projects to improve practice. BIM provides a series of functions for building projects, including handling building information and data (Goedert and Meadati 2008; Isikdag et al. 2007), integrating project process and delivery (Azhar 2011; Bryde et al. 2013), setting a collaborative environment (Liu et al. 2017; Sackey et al. 2014), adopting lean and sustainable construction (Inyim et al. 2014; Jin et al. 2017; Sacks et al. 2010), and improving value management (Kim et al. 2017; Park et al.

2017). However, the current implementation of BIM in the industry still faces several challenges. One of the agendas to advance BIM implementation into project management practice is to integrate BIM into the managerial systems and procedures of AECO projects (He et al. 2017; Mancini et al. 2017; Whyte and Hartmann 2017). In addition, Gholizadeh et al. (2017) indicated that the further application of BIM in practice requires a collaborative approach to exploit the potential of BIM. The life-cycle and multidisciplinary feature of the building project also requires a mechanism that can link BIM to the entire project process (Beach et al. 2017). Moreover, the key areas to managing BIM in projects remain to be clarified.

Although the knowledge domains of project management specifically define the management of the integration, scope, schedule, quality, resources, communications, risks, procurement, and stakeholders of a project (PMI 2017), the adoption of project management in the AECO project requires a tailored approach, particularly when BIM is introduced. Certain updates on the scope of work need to be clarified to implement BIM in project management. In the current study, the integration of BIM into the AECO project life cycle helps to realize a new paradigm of project management, namely, BIM-based project management (BPM). BPM integrates management requirements at distinct stages of a building project into the functional applications of BIM and achieves efficient project management using BIM models (Ma et al. 2015). Thus, the research questions of this study include:

- How BIM works in life-cycle project management?

- What are the major focused areas to integrate BIM into the AECO project?
- How can the integration of BIM into the project life cycle help to realize BPM?

Focusing on these questions, this research proceeds in three steps. First, the development of the conceptual framework through literature review gives an overview of how BIM works in life-cycle project management. Second, the following ethnographic action research develops a BIM roadmap for the project life cycle by systematically implementing BIM into the project. Third, pieces of evidence and implications are derived to improve and support the conceptual framework with the implementation of BIM into the project. These steps are linked to one another and work together in the present work to achieve system development and improvement.

Literature Review

Given the fragmented feature of the AECO industry (Egan 1998), project information management enabled by construction ICTs can change the conventional practice to achieve good performance and competitiveness (Stewart 2007). With the organization of building production as projects, the adoption of ICTs in building construction is inevitably associated with project management practices and managing information with ICT is related to the different aspects of the project. Therefore, an integrated approach is required to optimize the value of ICT in building project management (Ahuja et al. 2009; Froese 2010). Furthermore, with regard to ICT adoption in AECO projects, a few studies, such as Peansupap and Walker (2006) and Jacobsson et al. (2017) introduce frameworks to analyze and facilitate cooperation. BIM, as a widely used ICT in AECO, prevails in this research domain.

Impact and Benefits of BIM in AECO

Among the construction ICTs, BIM is interpreted as a disruptive technology that brings changes to the AECO project life cycle (Davies et al. 2017; Eastman et al. 2011; Gledson and Dawson 2017). The principal objective of BIM is to provide project teams with visual aids and to improve the AECO project environment with accurate data, simulation, and workflow analysis (Azhar 2011; Sacks et al. 2010). In addition to building information management, BIM can also provide a sociotechnical system to restructure the AECO project environment (Gu and London 2010; Liu et al. 2017; Sackey et al. 2014).

Several studies have clarified the benefits of BIM from the perspective of project management. Park and Lee (2017) compared two units in the same building project with different degrees of BIM involvement to demonstrate the substantial effect of BIM on building design coordination. Lu et al. (2015) quantified the impact of BIM to improve the efficiency of the project endeavor by comparing two cases with and without BIM. Bryde et al. (2013) reported that the application of BIM to projects contributes to good control of time, cost, and quality, along with enhanced communication and collaboration. Additionally, Inyim et al. (2014) inferred that BIM allowed project teams to manage comprehensive building data and information, and thereby achieve effective decision making in the design and construction process. Finally, Liu et al. (2017) confirmed the use of BIM to promote integrated project delivery through collaborative work.

BIM Implementation in Building Projects

The implementation of BIM in building projects faces barriers but gains achievements. The most common barriers of BIM implementation in building projects are the lack of vision, flexibility, and contextual certainty; reluctance to change; poor technology handling; and insufficient systematic support (Eadie et al. 2013; Fox and Hietanen 2007; Khosrowshahi and Arayici 2012). Meanwhile, several studies have focused on project-wise BIM implementation. For example, Gu and London (2010) introduced a decision framework for systematically implementing BIM. Taylor and Bernstein (2009) highlighted the importance of organizational efforts in BIM adoption by using a managerial approach. Moreover, Hartmann et al. (2012) summarized the multi-aspect views of BIM and suggested the alignment of BIM applications with construction processes. Interface techniques and tools, such as BIM servers (Singh et al. 2011), web services and networks (Chen and Hou 2014), and BIM overlay (Beach et al. 2017), are continuously introduced and adopted in AECO projects to enhance the effective collaboration of different project teams toward an integrated information management approach.

The integration of BIM into the project management practice is a systematic initiative. A minimal number of studies have aimed to specify the scope of work to systematically introduce BIM into a building project, particularly few from the life-cycle perspective of an AECO project. Although different types of BIM execution plans are developed and used to manage BIM in projects, a theoretical foundation is required to analyze and justify the planning approach.

Conceptual Framework

The information management of a building project requires a centralized approach (Jaafari and Manivong 1998). Ideally, a global BIM model for the building project, with all its details shared among project teams, is in favor of collaboration and communication (Ahn et al. 2015). However, the information needed by each team can be highly selective due to the different interests and needs of project teams, which results in various preferences of modeling information and data (MID) and different local BIM models to represent building parts. Hence, the association of global-local relations with BIM models can help to connect and organize them in building projects. The global model integrates building information from various disciplines, whereas the local models address the specific needs of different project teams. Therefore, the development of an alternative approach to the idealistic situation is imperative to serve the use of different BIM models in project management.

Given that BIM encompasses a series of aspects and elements, frameworks can accommodate the systematic implementation of BIM in projects. Oraee et al. (2017) identified five aspects, namely, actors, context, processes, tasks, and teams, to enable collaborative efforts in BIM-based building projects. Jung and Joo (2011) revealed that BIM frameworks accommodate different aspects and elements of the BIM process, which is essential to effective BIM implementation due to its functions of integrating resources and facilitating collaborative efforts. Correspondingly, the present research applies a conceptual framework to accommodate the systematic implementation of BIM into building projects. The conceptual framework consists of BIM Information Flow, BIM Model Chain, BIM Workflow, BIM Institutional Environment, and BIM-based Project Management Information System (PMIS).

BIM Information Flow

BIM Information Flow refers to structured information flow that is enabled through technical means for BIM modeling or the application of BIM to realize project management objectives. To efficiently model building information, technical issues such as the exchange of MID among different project teams are crucial as well as the management of BIM Information Flow to enable efficient information sharing and exchange. Also, related organizational and technical measures are necessary to ensure and facilitate BIM Information Flow.

Drew from related works, BIM Information Flow in BIM-based projects can be classified into two types. One type enables information and data exchange that directly serves the modeling process. Insights on this type of exchange focus on the interoperability issues of different aspects, such as information and data (e.g., Froese 2003; Pazlar and Turk 2008), data path and information channel (e.g., Lin et al. 2013), software (e.g., Gökçe et al. 2012), and building information modules (e.g., Eastman et al. 2009). In addition, Alsafouri and Ayer (2018) found that BIM-related information flow can be enhanced by other ICTs, such as radio frequency identification and mobile computing. Meanwhile, the implementation of BIM should be associated with project deliverables and objectives (Ahn et al. 2015). To implement BIM in project management, another type of BIM Information Flow exists to realize the purposes of project management, such as planning for project resources and deliverables (e.g., Ahn et al. 2015; Froese et al. 2002), decision making (e.g.,Gu and London 2010; Park et al. 2017), schedule and cost control (e.g.,Kim et al. 2017; Son et al. 2017), and collaborative working (e.g.,Isikdag et al. 2007; Nour 2009).

BIM Model Chain

BIM Model Chain represents a virtual chain of sequential evolutions of BIM models through different stages and disciplines in the integrated modeling process. The global BIM model becomes increasingly complex as a project proceeds through its life cycle. For example, a construction BIM model can be developed with the addition of construction-related building information into a design BIM model. As Fig. 1 illustrates, the global model enables the exchange of MID among different project teams throughout various stages of the project lifecycle, which helps to achieve integrated project information management. In this study, MID can either be information and data in diverse formats that can be processed with BIM or simply a local BIM model that encompasses the information and data of a discipline or a part of a building, such as a structural model or a foundation model. The interconnection of the global model and MID with BIM Information Flow makes the two clusters of information and data connected to each other. The concept forms the basis of the mapping of the relationship between the global model and MID.

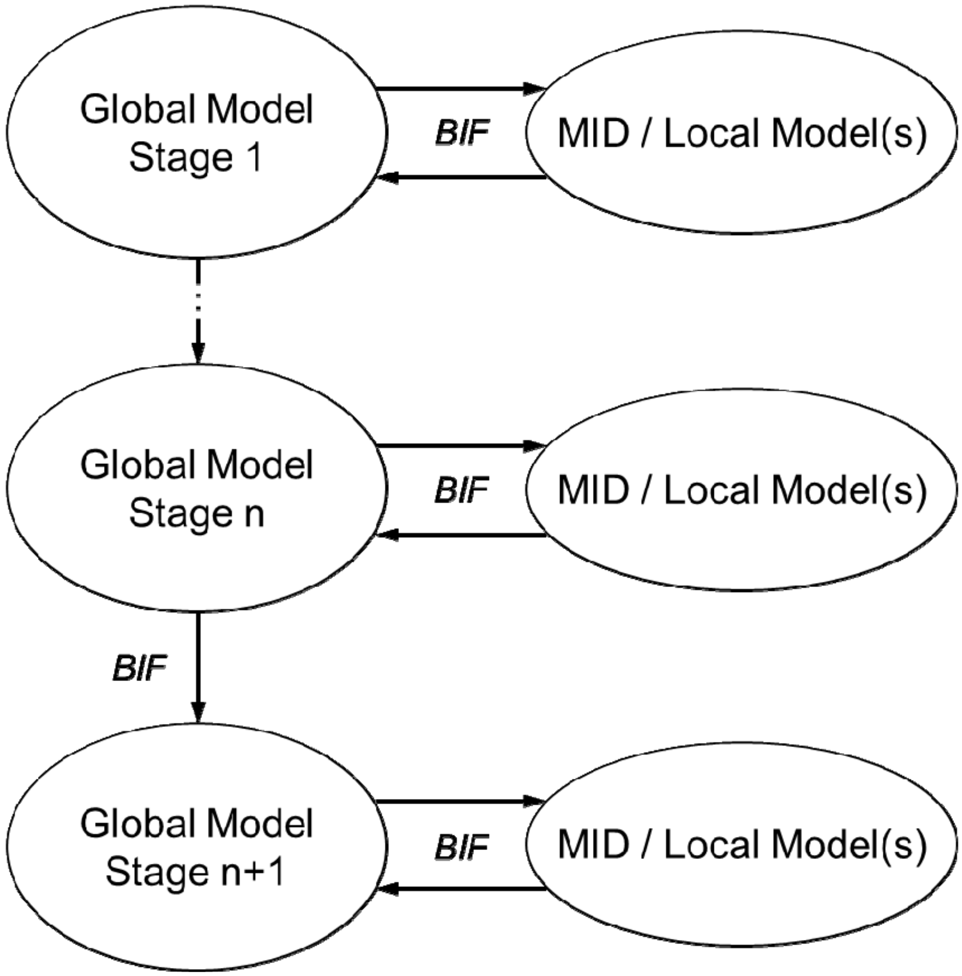

Fig 1. BIM Model Chain

A few research findings have supported BIM Model Chain. The BIM model, as a repository of building information and data, organizes information flow throughout a system to coordinate project efforts (Demian and Walters 2014). BIM promotes integration in projects; however, a project involves multiple project organizations with individual features and needs (Dossick and Neff 2009). The implementation of BIM into projects should also satisfy the specific requirements of different project teams. Correspondingly, Beach et al. (2017) suggested a semi-federated approach for the integration and distribution of MID.

BIM Workflow

BIM Workflow refers to the workflow of BIM process run by project teams with inputs and outputs for project management purposes. It is a concept that illustrates how BIM works in project management. Project teams rely on the global BIM model to gather and share information throughout the project life cycle. BIM Information Flow enables the modeling process to satisfy the demand for information processing, which shapes the workflow with the inflow and the outflow through the model (Fig. 2). In general, the input of the modeling process is MID, while the output is a functional application of BIM.

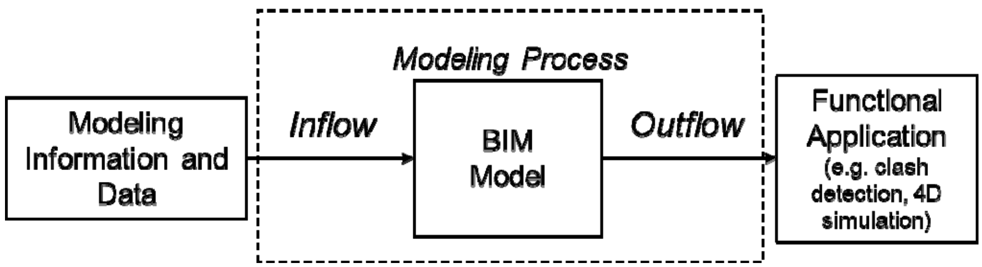

Fig 2. BIM Workflow

The content of BIM Workflow draws from some relevant studies. To manage BIM within the project context, Gu and London (2010) proposed a series of procedures to associate BIM with the requirements of different stages referring to the models, products, and activities. Cerovsek (2011) illustrated a basic model flow from 3D to 5D with inputs and outputs and coupled model flow with project properties, such as geometry, cost, and time. Porwal and Hewage (2013) described the changes of BIM models in construction with the inflow and outflow of building information.

BIM Institutional Environment

BIM Institutional Environment refers to the regulatory system formed by BIM-related standards, requirements, and rules to ensure BIM implementation within the project context (Table 1). The term “institutional environment” is defined as “characterized by the elaboration of rules and requirements to which individual organizations must conform if they are to receive support and legitimacy” (Scott 1995, p. 132). Institutional efforts in buildings include regulatory governance, standardization of the body of knowledge and codes of practice, and formation of organizational cultures and rules (Kadefors 1995). In the AECO industry, The institutional environment serves as a context for BIM adoption (Cao 2016; Sackey et al. 2014). Additionally, BIM governance (Alreshidi et al. 2017; Rezgui et al. 2013) applies to models and modeling-related processes for systematic and effective implementation of BIM into projects. An institutional environment within a BIM-based project is required to facilitate BIM governance and ensure collaborative working among project teams.

Several studies have discussed the requirements of regulation to govern BIM-related project procedures and deliverables. Succar (2009) employed the term “BIM policy” to describe the regulatory administration of BIM implementation. Moreover, the literature on BIM implementation encompasses standardizations (e.g.,Eastman et al. 2009; McCuen et al. 2011), technical requirements (e.g.,Dossick et al. 2014; Gu and London 2010; Singh et al. 2011), and organizational requirements (e.g.,Ahn et al. 2015; Son et al. 2015; Taylor and Bernstein 2009). These aspects are confirmed in the BIM governance framework by Alreshidi et al. (2017). Table 1 provides the content of BIM Institutional Environment along with detailed examples.

Table 1. Contents of BIM Institutional Environment

Concept	Contents	Detailed examples
BIM Institutional Environment	Standards and technical requirements	● Industry standards ● Levels of development for BIM models ● Information and data specifications
	Organizational rules and requirements	● Roles and responsibilities ● Hierarchy and work process
	Policy and legal issues	● Ownership and authorization ● Contractual agreements

BIM-based PMIS

BIM-based PMIS refers to an information system enabled by information technologies to support BIM Information Flow and associate BIM with project management practices. BIM Information Flow should be further enabled to serve its purpose in BIM Model Chain and BIM Workflow.

Different approaches have been adopted to enable BIM-based PMIS, such as BIM server (Singh et al. 2011), cloud BIM (Redmond et al. 2012), and P2P (peer-to-peer) technology (Chen and Hou 2014). The association of BIM with PMIS integrates miscellaneous design information, which is crucial for building construction (Whang et al. 2016). However, the implementation of BIM interface systems involves technical, administrative, and legal issues (Singh et al. 2011).

Concept Summary

Accordingly, the conceptual framework proposes five concepts that are BIM Information Flow, BIM Model Chain, BIM Workflow, BIM Institutional Environment, and BIM-based PMIS to accommodate BIM in building projects. Succar (2009) identified the major efforts for integrating BIM into projects including (1) enabling BIM modeling, (2) realizing collaborative working based on the BIM model, and (3) incorporating BIM into the project system. Based on these procedures, Table 2 highlights the major purposes and definitions of the key concepts in the conceptual framework.

Table 2. Concept summary of the conceptual framework

Key concepts	Major elements	Main purposes
BIM Information Flow	● Information and data ● Software ● Interoperability ● IDE path and channel	Enabling BIM in projects
BIM Model Chain	● Global model ● MID/ local models ● BIM information flow	Managing BIM throughout the project life cycle
BIM Workflow	● MID ● BIM model	Managing project work with BIM

	• Modeling process • Functional application	
BIM Institutional Environment	• Standards and technical requirements • Organizational rules and requirements • Policy and legal issues	Contextualizing BIM in projects
BIM-based PMIS	• Information technologies and interface systems • Technical, administrative and legal arrangements	Incorporating BIM into the information system

The Ethnographic Action Research: A Case of a BIM-based Building Project

Project Description and Data Collection

In the present study, the project focused on refurbishing an old office building owned by a local building research institute in Chengdu, China. The demand for BIM the application of BIM to project management originated not only from the complexity of the project which involved large-scale dismantlement, but also from the fact that the owner, as a building research institute, is interested in the implementation of BIM in the building project. Hence, the implementation of BIM in this case is a systematic endeavor toward the project life cycle but constrained to a specific budget.

Some of the authors served as BIM consultants to the owner with access to the project. These authors were mainly responsible for the development of a feasible project management approach that relies on BIM. The development of the research approach was an interactive process, during which the practitioners and researchers collaborate to work on this project.

The authors participated as consultants in the design stage of the project for approximately six months. Most of the evidence and implications were obtained through participative observation. The collection of data involved informal interviews, collective discussions during project meetings, document analyses, and reflections on practical situations.

Method Selection and Justification

This study uses an ethnographic action research approach to develop the project management system. This approach involves comprehensive literature review to identify the scope and concepts of the conceptual framework, action research in system development to probe into details, and ethnographic analysis to obtain an overview. Thus, this is a qualitative research, as the qualitative research method suits well for process analysis and context specification (Amaratunga et al. 2002). As part of the qualitative research method, the ethnographic approach is used in construction research to establish theories and inductively collect data through observation and interaction with peers (Phelps and Horman 2009).

The action research allows the exploration of new knowledge and impels the progress of the project. According to Hult and Lennung (1980), the purpose of action research was to address practical issues on a theoretical approach and frame a situation, thereby analyzing the pragmatic problem with regard to multiple aspects through observation and interference of the researchers. In the research domain of construction management, action research can be used to deal with practical issues and develop theories (Azhar et al. 2009).

Although the ideal experimental situation is to have two parallel projects to compare the results of the study, the chance is rare to have such a case. Therefore, the ethnographic action research method is selected, as it adopts the strategy to immerse in the practical context and develop the research results through the participation of problem-solving process (Tacchi et al. 2003).

Research Approach and Procedures

The major work of this research includes the development of project procedures and system with BIM. The research design refers to Tacchi et al. (2003) and Hartmann et al. (2009) to develop an ethnographic action research cycle. The research cycle includes steps as follows (Fig. 3):

- Reviewing the literature in related practical and academic background and planning of BIM implementation according to the objectives and requirements throughout the project life cycle;
- Coding of the main focused areas and work routines to develop a BIM roadmap of the project life cycle based on the conventional practice of project management;
- Adapting the BIM roadmap to the project and identifying the focused areas for exploration or improvement based on observations and reflections; and
- Starting over the research cycle with the literature review.

The conceptual framework has been developed through the steps above. We iteratively ran the research cycle by reviewing related studies to obtain new insights, analyzing evidence obtained from the building project, and identifying the concepts with the decoded focused areas. Consequently, the procedures are highly interdependent and influenced one another. In this paper, the conceptual framework is presented before the development of the BIM roadmap as a knowledge background for system development to maintain a simple logical flow in this study. The conceptual framework defines the scope of work for BIM-related issues through the implementation of the BIM roadmap. Moreover, evidence and implications have been derived via the process.

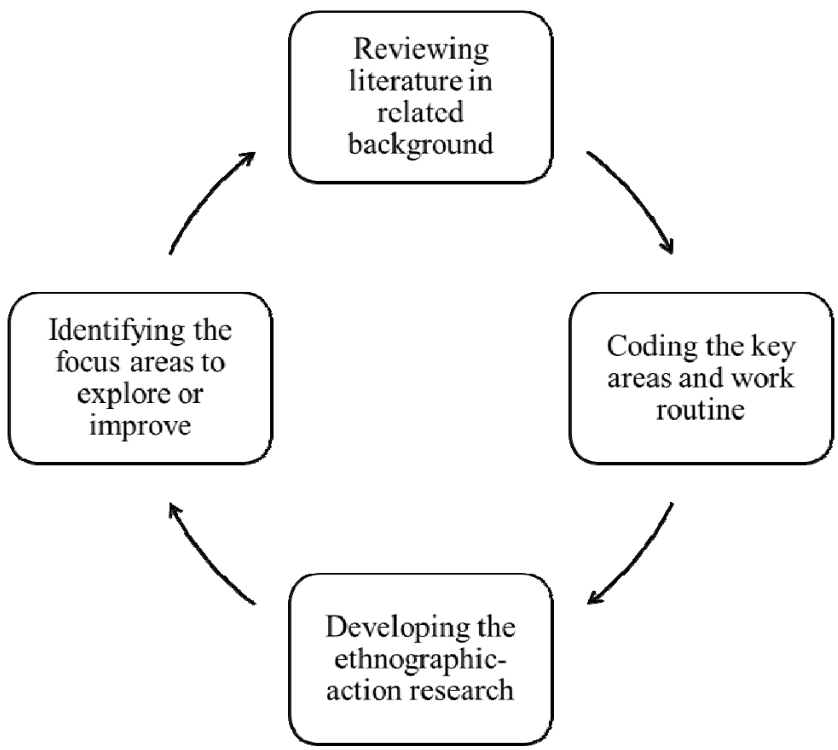

Fig 3. The ethnographic action research cycle for the current study

Findings of the Ethnographic Action Research: Development and Implementation of BIM Roadmap into the Project Life Cycle

This section documents the proceedings of the BIM-based building project, where some of the authors participated as consultants for the BIM implementation and related project management affairs. The idea is to work on the conventional project management approach and apply the BIM roadmap to the life cycle of the building project to achieve BPM.

Developing and Implementing the BIM Roadmap of the Project Life Cycle and Planning of Further Procedures

Through the development process, the action researchers designed a BIM roadmap for the project life cycle and implemented it together with the practitioners. The problems identified to enable the modeling process included: (1) how to exchange data and enhance interoperability; (2) how to utilize the information and data modeling for project management purposes, such as cost, schedule, and quality control; and (3) how to interface project teams and project procedures with BIM. Accordingly, the major effort is to satisfy the demand of different project teams for information sharing and communication and couple BIM applications with the practice of project management. In this project, the BIM roadmap (Fig. 4) includes different project stages through the project life cycle.

As BIM consultants for the project, the action researchers represented the owner to be responsible for BIM implementation through the project life cycle. The administration of the global model and related affairs was one of the main tasks. The MID for the original model came from the designer group who provided the basic building information, such as geometry and material information. After the action researchers had developed a basic architectural model with the designer, the model was enhanced with design information of various disciplines to enable clash detection. Hence, the design model of the building served as the original global model. As the project progressed, the global model became increasingly complicated in allowing functional applications of BIM to realize project objectives. As Fig. 4 shows, the development of the global model at different stages shapes a chain through the project life cycle. From left to right, the figure demonstrates the workflows of BIM at different stages. The arrow represents BIM Information Flow. A model chain is identified with the alternations of the global model throughout the project life cycle. The roadmap incorporated the workflows of BIM into the project life cycle, and technical codes and organizational rules were introduced to ensure the process.

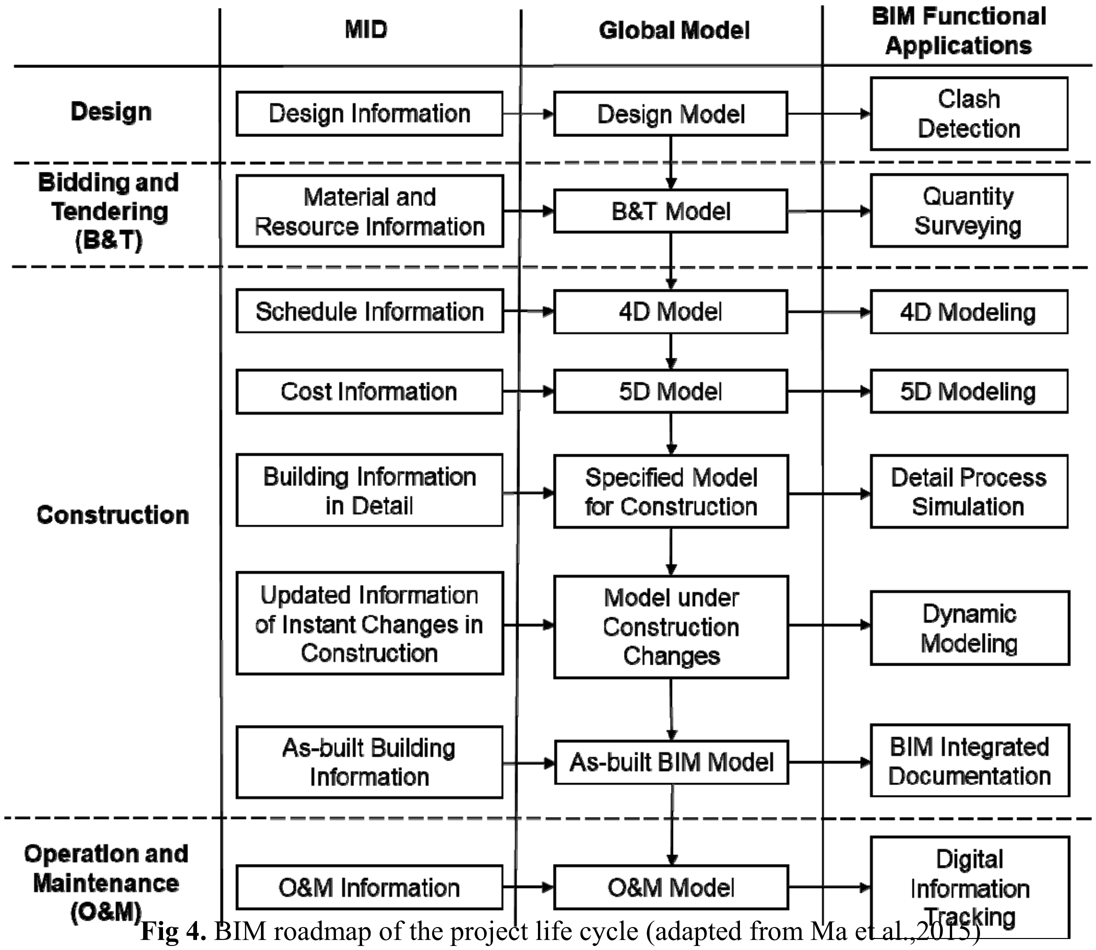

Fig 4. BIM roadmap of the project life cycle (adapted from Ma et al.,2015)

One more demand that originated from the project was the integration and interface for the BIM-based collaboration, which became phenomenal with the BIM roadmap identified. As proposed by the owner, a BIM platform at the succeeding stages can enhance the project cooperation. Hence, the need for a BIM-based PMIS was identified to support multidisciplinary group endeavors, such as approvals of project changes, documentation, and cost management for the construction process. The platform is an ICT system which enables the sharing of the project information including the MID. However, the key principle was that the models should have been modified directly upon the platform to mediate instant revisions. As an interface initiative, the platform was operated by representatives from different teams. Accordingly, the adoption of a centralized approach eased administration of the platform. Each team had one account with access to information from the global model. However, the BIM representative must go through the BIM consultant to modify the model. The platform was central to the system because it integrates the efforts of different teams; however, it was attached to regulation and specification to define organizational requirements, such as the permission of access and behavior norms. Moreover, detail specification of the technical requirements, including the accuracy and reliability of the model was undertaken. Additionally, project teams employed corresponding organizational and technical measures to adapt to this way of working.

Evidence and Implications from the Implementation

During the implementation, the owner and the BIM consultant encountered managerial, organizational, and technical issues. The first issue that emerged at the beginning was the interoperability of data and software. It required a major effort early in the project. Secondly, the continual actions on model development, modification, and handover ensured the proper development of the models to suit the project and enable BIM Information Flow for the modeling process. Thirdly, BIM implementation was attached to project objectives to ensure that the BIM worked for the project management purposes. During this stage, an application-oriented approach was adopted to ensure the implementation of BIM for project management purposes with functional applications. Before the construction, the key resorts of the owner to use BIM in project management was to realize functional applications, including clash detection and quantity surveying. Additionally, as a BIM-based PMIS, the platform addressed the needs of interfacing collaborative efforts at the succeeding stage. Also, through the entire process, a regulatory document specified as Project BIM Standard was in place to govern the BIM-related process, deliverables, requirements, and objectives.

Evidence showed that a BIM roadmap for the project life cycle was required to realize BPM and respond to the change in project context brought by the implementation of BIM. The conceptual framework formed from a set of BIM-related concepts, including BIM Information Flow, BIM Model Chain, BIM Workflow, and BIM Institutional Environment. It provided a theoretical foundation for the systematic implementation of BIM into project management. Moreover, BIM-based PMIS was in place to enable communication, integration, and collaboration. As Table 3 presents, the major actions taken in the project and the findings of the action research along with the evidence were in line with the key concepts.

Table 3. Identifying and verifying the sources of the conceptual framework with the ethnographic action research

Key concepts	Major actions/findings	Evidence
BIM Information Flow	Identifying demand for information sharing and communication among project teams at different project stages	The major effort on the interoperability of data and software to enable BIM
BIM Model Chain	Mapping the model chain to satisfy the requirements of information modeling throughout the project life cycle	Continual actions on model development, modification, and handover by different actors

BIM Workflow	Planning different functional applications that rely on BIM models to realize the purposes of project management	Clash detection and quantity surveying as key resorts of the owner to utilize BIM in project management before the construction
BIM Institutional Environment	Need to govern the systematic implementation of BIM into the project	Project BIM Standards with organizational and technical requirements as a response to the change in the project context
BIM-based PMIS	Demand for an ICT-based collaboration mechanism in which BIM can be modified	Introduction of the platform to enable communication and collaboration in the project

Discussion

Although project management has wide application in AECO projects, the best practice of project management requires further exploration due to the introduction of ICTs, notably BIM. Our work establishes a conceptual framework to integrate BIM into the project life cycle to realize BIM-based approach for project management. The conceptual framework includes a set of correlated concepts to incorporate BIM into the project life cycle. BIM Information Flow connects distinct parts of the model system. BIM Model Chain is a virtual vehicle for BIM to function throughout the project life cycle. BIM Workflow is the path in which BIM can work for project management purposes. BIM Institutional Environment provides a context for BIM to be implemented and used by the project organizations. BIM-based PMIS enables project teams to collaborate for work related to information management. Although existing studies involve a few elements of the conceptual framework, the concepts synthesize the elements and apply them in the context of an AECO project regarding workflow, timeline, organizational behavior, and information management. Thus, the conceptual framework accommodates all these elements to facilitate BIM implementation into project management and enable the BPM approach. Meanwhile, the different parts of this research, including framework conceptualization, system development, and system implementation, are difficult to be separated from one another. The conceptual framework serves as a guideline for the development of the BIM roadmap. The implementation of a BIM roadmap also needs further measures and continuous improvement to adopt a specific project. The procedures are iterative and interdependent in working as a holistic mechanism to realize BPM.

Moreover, this study relates BIM to project management, which can contribute to the understanding and implementation of BIM in AECO projects. In the present study, BIM is an advanced means to store and share building information against project uncertainty. According to some classical works of organization design (Galbraith 1974; Tushman and Nadler 1978), information processing against task uncertainty can influence the structure of an organization. As BIM is a means of information processing, the introduction of BIM into a project requires an effort to offset the disruptiveness. The implementation of BIM is a trade-off between information management effort and project uncertainty. This is one theoretical implication that the implementation of BIM can disrupt an AECO project, and the conceptual framework explains how BIM reshapes the information processing procedures and related organizational structure.

However, the contribution of this research extends beyond the discipline of project management to include BIM adoption and integration. The conceptual framework identifies the focused areas to implement BIM in projects systematically and provides a theoretical basis to escalate the implementation of BIM from disciplinary modeling level to integrated collaboration level. Thus, the application of BIM helps promote collaborative working and enhance communication among different disciplines and teams by integrating BIM efforts into the project procedures and deliveries. Furthermore, the conceptual framework rationalizes BIM adoption from the perspective of project management and introduces new concepts to understand and plan BIM execution in AECO projects. All these accomplishments can inspire efficient management of the AECO practice and very few studies elaborate the mechanism of systematic BIM implementation with an approach orienting at the life-cycle practice of an AECO project.

Lastly, since this study has been conducted within the Chinese construction industry, relevant recent works are investigated to benchmark its contribution to international BIM research and practice. Also under the Chinese construction context, Liu et al. (2017) identify the impact of BIM on the organizational, technical, and process aspects of the project, which is reflected in our conceptual framework. Moreover, the necessity of BIM Institutional Environment is coherent with one conclusion from Park and Lee (2017) to emphasize the importance of BIM environment with organizational and technical measures for building design in the Korean context. Furthermore, the roadmap approach illustrated in this study indicates that the adoption of BIM involves project decisions, which is consistent with the findings of Davies and Harty (2013) with a case from the UK. Based on data collected from New Zealand and Australia, Davies et al. (2017) suggest the implementation of BIM into projects relate to work culture, where a project-based framework is required to provide a context for relevant efforts. Additionally, Poirier et al. (2017) explore a Canadian project and demonstrate the influence of BIM implementation on project teams, thereby reflecting how information is reorganized, and refreshing the practice of information management. This finding can partially confirm BIM Information Flow and BIM Workflow.

Conclusions

BIM provides a series of functional applications to advance project management practice. Among the various functions and benefits of BIM, managing information, facilitating communication, and interfacing multi-disciplinary cooperative efforts are necessary for implementing project management. Through the ethnographic action research, a conceptual framework is established and tested with the exploration of BIM integration into the project life cycle and a project BIM roadmap is exemplified.

The conceptual framework that underlies the BIM roadmap has theoretical and practical implications for project management. The conceptual framework analyzes how BIM works in life-cycle project management and provides a theoretical foundation to facilitate further research in the implementation of BIM in project management practice, with the introduction of the five BIM-related concepts that are BIM Information Flow, BIM Model Chain, BIM Workflow, BIM Institutional Environment, and BIM-based PMIS. The conceptual framework can also be applied to identify the major scope of work for BIM roadmap development and diagnose problems in the project-wise implementation of BIM.

In implementing the conceptual framework in this research project, BIM models and building information of different disciplines are integrated, which in further enhances the multidisciplinary collaboration. This study examines the integration of BIM into the life cycle of a building project with a few limitations though. First, the project involves complex dismantlement and refurbishment work which makes the accurate simulation of related building information difficult; hence, the use of BIM models in the construction stage is restricted. Second, the BIM models in this project serve as references rather than official sources of information for practices due to the influence of work culture, which provides another evidence for "hybrid practice" in BIM-based building projects, as Davies et al. (2017) articulated. Third, the BIM roadmap is a case-specific application of the conceptual framework to integrate BIM into the project life cycle; however, it sets an example to integrate BIM into the life cycle of an AECO project. Thus, we regard this research as a pilot project for BPM.

Finally, this research mainly focuses on the conceptual framework that identifies the areas for managing BIM in building projects and sets a theoretical foundation for BPM. Given that this research is at a conceptual level, details on BIM implementation from other peer projects would generate further implications that may advance the exploration of BPM. Future research can also focus on the organizational change of projects with the systematic implementation of BIM or other aspects of the BPM paradigm.

Acknowledgments

This study drew inspiration from some of the authors who presented at the 6th International Conference on Construction Engineering and Project Management in Busan, Republic of Korea. This research forms part of a joint Ph.D. program of Sichuan University and The Hong Kong Polytechnic University funded by the Hong Kong Jockey Club. The authors would like to thank Dr. Wong Kam Din from the Department of Building and Real Estate of The Hong Kong Polytechnic University for his comments on this study.

References

Ahn, Y. H., Kwak, Y. H., and Suk, S. J. (2015). "Contractors' transformation strategies for adopting building information modeling." *Journal of management in engineering*, 32(1), 05015005.

Ahuja, V., Yang, J., and Shankar, R. (2009). "Benefits of collaborative ICT adoption for building project management." *Construction Innovation*, 9(3), 323-340.

Alreshidi, E., Mourshed, M., and Rezgui, Y. (2017). "Factors for effective BIM governance." *Journal of Building Engineering*, 10, 89-101.

Alsafouri, S., and Ayer, S. K. (2018). "Review of ICT Implementations for Facilitating Information Flow between Virtual Models and Construction Project Sites." *Automation in Construction*, 86, 176-189.

Alshawi, M., and Ingirige, B. (2003). "Web-enabled project management: An emerging paradigm in construction." *Automation in construction*, 12(4), 349-364.

Amaratunga, D., Baldry, D., Sarshar, M., and Newton, R. (2002). "Quantitative and qualitative research in the built environment: application of “mixed” research approach." *Work study*, 51(1), 17-31.

Azhar, S. (2011). "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry." *Leadership and management in engineering*, 11(3), 241-252.

Azhar, S., Ahmad, I., and Sein, M. K. (2009). "Action research as a proactive research method for construction engineering and management." *Journal of Construction Engineering and Management*, 136(1), 87-98.

Beach, T., Petri, I., Rezgui, Y., and Rana, O. (2017). "Management of Collaborative BIM Data by Federating Distributed BIM Models." *Journal of Computing in Civil Engineering*, 31(4), 04017009.

Bryde, D., Broquetas, M., and Volm, J. M. (2013). "The project benefits of building information modelling (BIM)." *International Journal of Project Management*, 31(7), 971-980.

Cao, D. (2016). "Institutional drivers and performance impacts of BIM implementation in construction projects: An empirical study in China." The Hong Kong Polytechnic University.

Cerovsek, T. (2011). "A review and outlook for a ‘Building Information Model’(BIM): A multi-standpoint framework for technological development." *Advanced engineering informatics*, 25(2), 224-244.

Chen, H.-M., and Hou, C.-C. (2014). "Asynchronous online collaboration in BIM generation using hybrid client-server and P2P network." *Automation in Construction*, 45, 72-85.

Davies, K., McMeel, D. J., and Wilkinson, S. (2017). "Making friends with Frankenstein: Hybrid practice in BIM." *Engineering, Construction and Architectural Management*, 24(1), 78-93.

Davies, R., and Harty, C. (2013). "Implementing 'Site BIM': a case study of ICT innovation on a large hospital project." *Automation in Construction*, 30, 15-24.

Demian, P., and Walters, D. (2014). "The advantages of information management through building information modelling." *Construction Management and Economics*, 32(12), 1153-1165.

Dossick, C. S., Anderson, A., Azari, R., Iorio, J., Neff, G., and Taylor, J. E. (2014). "Messy talk in virtual teams: achieving knowledge synthesis through shared visualizations." *Journal of Management in Engineering*, 31(1), A4014003.

Dossick, C. S., and Neff, G. (2009). "Organizational divisions in BIM-enabled commercial construction." *Journal of construction engineering and management*, 136(4), 459-467.

Eadie, R., Odeyinka, H., Browne, M., McKeown, C., and Yohanis, M. (2013). "An analysis of the drivers for adopting building information modelling." *Journal of Information Technology in Construction (ITcon)*, 18(17), 338-352.

Eastman, C., Jeong, Y.-S., Sacks, R., and Kaner, I. (2009). "Exchange model and exchange object concepts for implementation of national BIM standards." *Journal of Computing in Civil Engineering*, 24(1), 25-34.

Eastman, C. M., Eastman, C., Teicholz, P., and Sacks, R. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*, John Wiley & Sons.

Egan, J. (1998). "The Egan report-rethinking construction." *Report of the construction industry task force to the deputy prime minister*. London.

Fox, S., and Hietanen, J. (2007). "Interorganizational use of building information models: Potential for automational, informational and transformational effects." *Construction Management and Economics*, 25(3), 289-296.

Froese, T. (2003). "Future directions for IFC-based interoperability." *Journal of Information Technology in Construction (ITcon)*, 8(17), 231-246.

Froese, T., Grobler, F., Ritzenthaler, J., Yu, K., Akinci, B., Akbas, R., Koo, B., Barron, A., and Kunz, J. (2002). "Industry foundation classes for project management-a trial implementation." *Journal of Information Technology in Construction (ITcon)*, 4(2), 17-36.

Froese, T. M. (2010). "The impact of emerging information technology on project management for construction." *Automation in construction*, 19(5), 531-538.

Gökçe, K. U., Gökçe, H. U., and Katranuschkov, P. (2012). "IFC-based product catalog formalization for software interoperability in the construction management domain." *Journal of computing in civil engineering*, 27(1), 36-50.

Galbraith, J. R. (1974). "Organization design: An information processing view." *Interfaces*, 4(3), 28-36.

Gholizadeh, P., Esmaeili, B., and Goodrum, P. (2017). "Diffusion of Building Information Modeling functions in the construction industry." *Journal of Management in Engineering*, 34(2), 04017060.

Gledson, B. J., and Dawson, S. (2017). "Use of simulation through BIM-enabled virtual projects to enhance learning and soft employability skills in architectural technology education." *Building Information Modelling, Building Performance, Design and Smart Construction*, Springer, 79-92.

Goedert, J. D., and Meadati, P. (2008). "Integrating construction process documentation into building information modeling." *Journal of construction engineering and management*, 134(7), 509-516.

Gu, N., and London, K. (2010). "Understanding and facilitating BIM adoption in the AEC industry." *Automation in construction*, 19(8), 988-999.

Hartmann, T., Fischer, M., and Haymaker, J. (2009). "Implementing information systems with project teams using ethnographic–action research." *Advanced Engineering Informatics*, 23(1), 57-67.

Hartmann, T., Van Meerveld, H., Vossebeld, N., and Adriaanse, A. (2012). "Aligning building information model tools and construction management methods." *Automation in construction*, 22, 605-613.

He, Q., Wang, G., Luo, L., Shi, Q., Xie, J., and Meng, X. (2017). "Mapping the managerial areas of Building Information Modeling (BIM) using scientometric analysis." *International Journal of Project Management*, 35(4), 670-685.

Hult, M., and Lennung, S. Å. (1980). "Towards a definition of action research: a note and bibliography." *Journal of management studies*, 17(2), 241-250.

Inyim, P., Rivera, J., and Zhu, Y. (2014). "Integration of building information modeling and economic and environmental impact analysis to support sustainable building design." *Journal of Management in Engineering*, 31(1), A4014002.

Isikdag, U., Aouad, G., Underwood, J., and Wu, S. (2007).“Building information models: A review on storage and exchange mechanisms.”Proc., 24th CIB-W78 Conf. on Information Technology in Construction, University of Maribor, Maribor, Slovenia.

Jaafari, A., and Manivong, K. (1998). "Towards a smart project management information system." *International journal of project management*, 16(4), 249-265.

Jacobsson, M., Linderoth, H. C., and Rowlinson, S. (2017). "The role of industry: An analytical framework to understand ICT transformation within the AEC industry." *Construction Management and Economics*, 1-16.

Jin, R., Hancock, C., Tang, L., Chen, C., Wanatowski, D., and Yang, L. (2017). "Empirical study of BIM implementation–based perceptions among Chinese practitioners." *Journal of Management in Engineering*, 33(5), 04017025.

Jung, Y., and Joo, M. (2011). "Building information modelling (BIM) framework for practical implementation." *Automation in Construction*, 20(2), 126-133.

Kadefors, A. (1995). "Institutions in building projects: Implications for flexibility and change." *Scandinavian Journal of Management*, 11(4), 395-408.

Khosrowshahi, F., and Arayici, Y. (2012). "Roadmap for implementation of BIM in the UK construction industry." *Engineering, Construction and Architectural Management*, 19(6), 610-635.

Kim, S., Chin, S., Han, J., and Choi, C.-H. (2017). "Measurement of Construction BIM Value Based on a Case Study of a Large-Scale Building Project." *Journal of Management in Engineering*, 33(6), 05017005.

Lin, Y.-H., Liu, Y.-S., Gao, G., Han, X.-G., Lai, C.-Y., and Gu, M. (2013). "The IFC-based path planning for 3D indoor spaces." *Advanced Engineering Informatics*, 27(2), 189-205.

Liu, Y., van Nederveen, S., and Hertogh, M. (2017). "Understanding effects of BIM on collaborative design and construction: An empirical study in China." *International Journal of Project Management*, 35(4), 686-698.

Lu, W., Fung, A., Peng, Y., Liang, C., and Rowlinson, S. (2015). "Demystifying construction project time–effort distribution curves: BIM and non-BIM comparison." *Journal of Management in Engineering*, 31(6), 04015010.

Lu, Y., Li, Y., Skibniewski, M., Wu, Z., Wang, R., and Le, Y. (2014). "Information and communication technology applications in architecture, engineering, and construction organizations: A 15-year review." *Journal of Management in Engineering*, 31(1), A4014010.

Ma, X., Xiong, F., and Dong, N. (2015). "Exploring a BIM-based approach of project management.", Proc., Proceedings of the 6th International Conference on Construction Engineering and Project Management, Korea Institute of Construction Engineering and management, Busan, Republic of Korea.

Mancini, M., Wang, X., Skitmore, M., and Issa, R. (2017). "Editorial for IJPM special issue on advances in building information modeling (BIM) for construction projects." International Journal of Project mangement, 35(4), 656–657

McCuen, T. L., Suermann, P. C., and Krogulecki, M. J. (2011). "Evaluating award-winning BIM projects using the national building information model standard capability maturity model." *Journal of Management in Engineering*, 28(2), 224-230.

Nour, M. (2009). "Performance of different (BIM/IFC) exchange formats within private collaborative workspace for collaborative work." *Journal of Information Technology in Construction (ITcon)*, 14(48), 736-752.

Oraee, M., Hosseini, M. R., Papadonikolaki, E., Palliyaguru, R., and Arashpour, M. (2017). "Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review." *International Journal of Project Management*, 35(7), 1288-1301.

Park, C.-S., Kim, H.-J., Park, H.-T., Goh, J.-H., and Pedro, A. (2017). "BIM-based idea bank for managing value engineering ideas." *International Journal of Project Management*, 35(4), 699-713.

Park, J. H., and Lee, G. (2017). "Design coordination strategies in a 2D and BIM mixed-project environment: Social dynamics and productivity." *Building Research & Information*, 1-18.

Pazlar, T., and Turk, Ž. (2008). "Interoperability in practice: Geometric data exchance using the IFC standard." *Journal of Information Technology in Construction (ITcon)*, 13(24), 362-380.

Peansupap, V., and Walker, D. H. (2006). "Innovation diffusion at the implementation stage of a construction project: A case study of information communication technology." *Construction management and economics*, 24(3), 321-332.

Phelps, A. F., and Horman, M. J. (2009). "Ethnographic theory-building research in construction." *Journal of Construction Engineering and Management*, 136(1), 58-65.

Pich, M. T., Loch, C. H., and Meyer, A. D. (2002). "On uncertainty, ambiguity, and complexity in project management." *Management science*, 48(8), 1008-1023.

PMI. (2017). A guide to the project management body of knowledge (PMBOK guide 6th Edition). Project Management Institute.

Poirier, E. A., Forgues, D., and Staub-French, S. (2017). "Understanding the impact of BIM on collaboration: a Canadian case study." *Building Research & Information*, 1-15.

Porwal, A., and Hewage, K. N. (2013). "Building Information Modeling (BIM) partnering framework for public construction projects." *Automation in Construction*, 31, 204-214.

Redmond, A., Hore, A., Alshawi, M., and West, R. (2012). "Exploring how information exchanges can be enhanced through Cloud BIM." *Automation in Construction*, 24, 175-183.

Rezgui, Y., Beach, T., and Rana, O. (2013). "A governance approach for BIM management across lifecycle and supply chains using mixed-modes of information delivery." *Journal of Civil Engineering and Management*, 19(2), 239-258.

Sackey, E., Tuuli, M., and Dainty, A. (2014). "Sociotechnical systems approach to BIM implementation in a multidisciplinary construction context." *Journal of management in engineering*, 31(1), A4014005.

Sacks, R., Radosavljevic, M., and Barak, R. (2010). "Requirements for building information modeling based lean production management systems for construction." *Automation in construction*, 19(5), 641-655.

Scott, W. R. (1995). *Institutional theory and organizations.* Thousand Oaks, CA:Sage

Singh, V., Gu, N., and Wang, X. (2011). "A theoretical framework of a BIM-based multi-disciplinary collaboration platform." *Automation in construction*, 20(2), 134-144.

Son, H., Kim, C., and Kwon Cho, Y. (2017). "Automated schedule updates using as-built data and a 4D building information model." *Journal of Management in Engineering*, 33(4), 04017012.

Son, H., Lee, S., and Kim, C. (2015). "What drives the adoption of building information modeling in design organizations? An empirical investigation of the antecedents affecting architects' behavioral intentions." *Automation in Construction*, 49, 92-99.

Stewart, R. A. (2007). "IT enhanced project information management in construction: Pathways to improved performance and strategic competitiveness." *Automation in Construction*, 16(4), 511-517.

Succar, B. (2009). "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Automation in construction*, 18(3), 357-375.

Tacchi, J. A., Slater, D., and Hearn, G. N. (2003). *Ethnographic action research: A user’s handbook*, Unesco.

Taylor, J. E., and Bernstein, P. G. (2009). "Paradigm trajectories of building information modeling practice in project networks." *Journal of Management in Engineering*, 25(2), 69-76.

Tushman, M. L., and Nadler, D. A. (1978). "Information processing as an integrating concept in organizational design." *Academy of management review*, 3(3), 613-624.

Whang, S.-W., Flanagan, R., Kim, S., and Kim, S. (2016). "Contractor-Led Critical Design Management Factors in High-Rise Building Projects Involving Multinational Design Teams." *Journal of Construction Engineering and Management*, 143(5), 06016009.

Whyte, J. K., and Hartmann, T. (2017). "How digitizing building information transforms the built environment." Building Research & Information, 45(6), 591-595