



Review of ICT Implementations for Facilitating Information Flow between Virtual Models and Construction Project Sites

Suleiman Alsafouri^{a,*}, Steven K. Ayer^b

^a Virtual Design and Construction Project Engineer, Corbins Electric, AZ, United States

^b School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 873005, Tempe, AZ 85281, United States

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ABSTRACT

Information and communications technology (ICT) has had major effects on the architecture, engineering, and construction (AEC) research fields in recent decades, but a comprehensive and in-depth review of how ICT has been used to enable different modes of information flow on project sites is missing from the current literature. To fill this gap, this paper defines a systematic approach for classifying information flow modes and uses this method to determine trends in information communication modes reported in recent publications. These trends were determined through the identification and analysis of 119 journal articles published between 2005 and 2015 in order to determine the mode of information flow reported. The results show that the majority of papers (70.6%) report a unidirectional flow of information, while a much smaller portion report one of two bidirectional information flow modes (26.9% non-automated, and 2.5% automated). The contribution of this work is in systematically defining current trends in ICT publications related to information flow and also in the identification of the typical technologies used to enable these communication modes.

1. Introduction

Information and communications technology (ICT) has been increasingly applied in the construction industry. Complex modern construction information technologies such as Radio Frequency Identification (RFID), 3D Laser Scanning, Augmented Reality (AR), and Mobile Computing have been employed to manage data, improve project efficiency, reduce cost, minimize risk, and develop new construction processes. However, despite many successful implementations of these technologies in construction projects, construction project stakeholders still face a wide range of communication challenges when implementing ICT in their projects. Such challenges include: Fragmentation of the industry and lack of integration between the design and production processes [1]. Additionally, the physical environment within which the technology must operate, the multiple stakeholders collaborating on and off site, and technical content communication-transfer problems [2]. However, getting the right information to the right place also means overcoming the challenges of organizational fragmentation that is so common in the industry due to the site-based nature of the work. Therefore, understanding how different ICTs influence project information coordination in various project phases, as well as in the transferring of information between physical and model sites, would allow ICT implementation to improve, not

hinder, communication between project stakeholders and allow for more successful construction projects in the future.

For these reasons, the classification scheme in this research categorizes journal articles according to their bidirectional or unidirectional uses of ICTs, therefore allowing the authors to assess how different ICT implementations facilitate project information flow using a single or a combination technology of ICTs.

ICTs allow project data to be transmitted to and/or from a building site. A user can read information from either a virtual model or from an on-site device. To better understand how this data transfer has been implemented in prior works, this research proposed a classification system with four different modes of communication with the use of ICT. The first two modes relate to instances where project data is read only from a project site or virtual model. The second two relate to instances where the same data may be accessed from both the model and the site. Fig. 1 illustrates the conceptual information flow between physical construction sites and virtual model environments.

The four modes of communication are listed below with examples and explanations of how each one defined information coordination flow in prior works.

- Unidirectional-Model Coordination: Information flows from a virtual model or Building Information Modeling (BIM) to a physical site

* Corresponding author.

E-mail addresses: s.alsafouri@corbinselectric.com (S. Alsafouri), steven.ayer@asu.edu (S.K. Ayer).

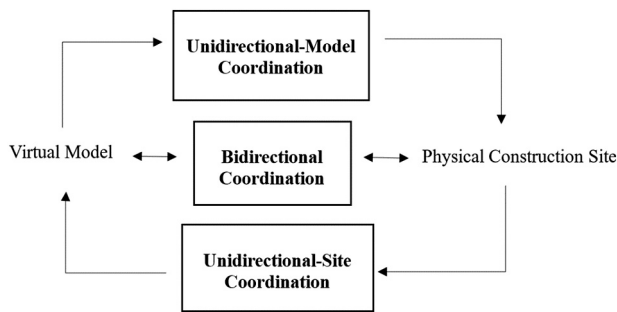


Fig. 1. Unidirectional and bidirectional information communication flow.

so the model's information and geometry can be presented and navigated on-site. For example: Using a mobile computer to navigate a BIM on-site for coordination model reference.

- **Unidirectional-Site Coordination:** Information is obtained from the physical site and is inputted into the virtual model. For example: Using RFID tags on precast concrete to update material tracking statuses.
- **Non-automated Bidirectional Coordination:** Information can be authored or accessed in either a virtual model or physical site environment, but a (human) user is needed to update the captured information. Generally, bidirectional information flow consists of data capturing, data transferring, and integrated data processing in both directions. In non-automated bidirectional coordination, the user is needed to transfer and incorporate captured data to the virtual model contents and vice versa. For example: Using a laser scanner to generate point clouds that a human user can combine with BIM content in a common visualization environment for existing conditions modeling and visualization. If there is no automated process used to update the visualization environment from the captured data, the user acts as an agent to update information content.
- **Automated Bidirectional Coordination:** Information flows between a virtual model and the physical site, but is authored without human intervention. In this type of coordination, data transferring, integrating, and processing phases are automated processes. For example: Using a site-based laser scanner to generate daily point clouds that can automatically be combined with BIM schedule information, resulting in an automatically generated 4D object-oriented progress tracking system.

Several recent publications have explored the use of ICTs to facilitate unidirectional-model coordination [3,4]. These studies explored how ICTs can be used to relay BIM content to field personnel. Based on the analysis strategy used in this paper, these BIM-based studies would fall into a unidirectional-model mode of communication. However, this paper focuses on the use of ICTs related to *site-based* communication to address the following research questions:

- How have ICTs been used to facilitate site-based communication between building project team members on site and those off site working in virtual model environments?
- Based on this analysis, what ICTs have been most commonly leveraged to facilitate different modes of project data flow?

To address these research questions, 119 scholarly publications from 2005 to 2015 were analyzed and categorized based on the data flow behaviors related to site-based information generation described in each publication. This paper, then, illustrates how recent research efforts have employed specific ICTs and combinations of ICTs to facilitate different modes of project information data flow and communication, and furthermore, which particular strategies are becoming well-established in current site-based ICT research.

2. Background & motivation

ICTs provide new opportunities for collecting and leveraging project data and creating business innovation [5]. Implementing appropriate technologies can lead to better oversight for specific construction tasks or design changes during the construction phase, thus enhancing project control and the construction process [6–8]. Moreover, these technologies may offer new solutions for effective decision-making techniques, fast measuring speed, noncontact measurement, moderate accuracy and automation that could change the current approach to construction [6,9]. Research also suggests that ICTs offer productivity gains of 31 to 45% when properly implemented [10].

The potential benefits that ICTs offer have pushed researchers to explore their use in the building industry. For example, in one study that reviewed AEC-related ICT research from 1998 to 2012 [11], several key ICTs were identified as having an effect on industry adoption, including: Wireless Technology, Virtual Reality (VR), BIM, Web, and Electronic Data Management System. Another ICT study identified emerging ICTs with the potential to automate building construction tasks [12], including: Global Positioning Systems (GPS), Wireless Technology, Radio Frequency Identification (RFID), Augmented Reality, and BIM. It has also been suggested that ICTs improve project performance by creating a closed loop information cycle between the physical construction site and corresponding virtual model [13,14], which may further support construction automation. This bidirectional flow of project data may also play a key role in improving project efficiency [15].

These suggested benefits have lead researchers to implement various technologies to facilitate project communication. To determine appropriate technologies for this analysis, prior literature that identified relevant ICTs were explored [11,12]. From these prior studies, seven ICTs that were common among the studies were identified, including: RFID, 3D laser scanning, Quick Response (QR) Codes, Augmented Reality (AR), Mobile Computing, Robotics (drones), and Wireless Connection. Examples of research and industrial pilot projects that have reviewed the potential of these technologies in the AEC industry are listed in Table 1.

3. ICTs classification characteristics

Prior research has studied the effectiveness of ICTs and their implementation in the industry. These studies proposed different methods of ICT categorization based on various criteria, characteristics, and use-case schemes to understand their adoption in the industry. Various benefits have been observed by categorizing the ways in which ICTs have been implemented, such as having a better plan for technology, understanding future technology trends, planning for specific projects, and analyzing markets and technologies for potential competitive advantages [39].

In general, the categorization characteristics in these studies were developed on the basis of the main themes, methods, and proposed directions of the research methodologies adopted by the researchers. For example, Lu et al. [11] categorized ICTs based on the factors that most noticeably influenced the success of ICT adoption and diffusion in AEC organizations. Other research studied ICTs based on human communication interfaces [2]. Table 2 presents the categories and characteristics used to understand ICT implementation in prior studies.

While various studies look at ICT adoption and their implementation (Table 2), the current literature lacks studies on how ICTs facilitate information coordination flow between virtual models and physical sites. This review paper aims to fill that gap and proposes a classification system using seven selected ICTs according to communication coordination schemas between virtual models and physical sites.

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