Automation in Construction 93 (2018) 241–251

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Linking radio-frequency identification to Building Information Modeling: Status quo, development trajectory and guidelines for practitioners

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ARTICLE INFO

Keywords:
Radio-frequency identification (RFID)
Building information modeling (BIM)
Linking RFID to BIM
Systematic review
Guidelines

ABSTRACT

The global construction industry has witnessed the prolific development of radio-frequency identification (RFID), building information modeling (BIM), and most recently, linkage of the two. However, comparatively little attention has been paid to understanding the status quo and development trajectory of such RFID-enabled BIM systems. In view of the proliferation of existing RFID, BIM, and information linkage, practitioners would benefit from guidelines for choosing systems so that their construction engineering and management (CEM) needs can be better met. Accordingly, the study described in this paper has two interconnected research aims: (1) to identify current patterns and development trends in RFID-enabled BIM systems; and (2) to develop guidelines for choosing appropriate solutions for different CEM scenarios. A review of 42 actual cases published in scholarly papers reveals that RFID, used to identify objects and improve real-time information visibility and traceability, is now increasingly linked to BIM as a central information platform. This study provides practitioners with five-step guidelines for linking RFID to BIM for various CEM needs. It also provides researchers with a point of departure for further exploration of approaches to enhancing the value of RFID, BIM, and the integration of one with the other.

1. Introduction

Building information modeling (BIM) and radio-frequency identification (RFID) have been receiving considerable and increasing attention from researchers and practitioners over the last decade or so. According to the NIBS [48], BIM is “a digital representation of physical and functional characteristics of a facility. BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition”. Goedert and Meadati [25] characterize BIM as an ideal information hub, enabling retrieval and display of essential information in formats consistent with the needs of managers. This information may be geometric, semantic, or topological [60,73], and to support decision-making throughout the facility's lifecycle it must be continually updated to reflect the facility's as-built condition. The interoperability of BIM can improve communication among parties [2–4]. As a digital platform, BIM can also retain information or knowledge (e.g., the design rationale). Further, it can be used to improve quality control [10], enhance safety management [38], and help construction waste estimation [40].

RFID uses radio waves to read and capture data. The three main components of a typical RFID system are: (1) a RFID tag or transporter carrying ID or other information; (2) a two-way radio transmitter-receiver, known as a reader or interrogator; and (3) a backend system that stores and processes the information for various applications [23]. An RFID system can operate at different bandwidths, from narrow to ultra-wide (UWB). A narrow-band RFID system can be further categorized as low frequency (LF), high frequency (HF), ultra-high frequency (UHF), or microwave (MW). RFID tags can be passive (without batteries) or active (with built-in batteries), depending on the power supply. RFID systems are contactless, independent of line of sight, and robust in harsh conditions [35]. In addition, multiple tags can be read simultaneously. Cost aside, RFID systems have advantages over barcodes, QR codes, and other auto-ID technologies [24]. Chief among these advantages is that RFID systems increase real-time information visibility and traceability [39]. Consequently, industries such as manufacturing, agriculture, and healthcare are making use of RFID systems for identification, tracking, locating, and recording [58,74,77,79]; as is the construction industry [35,26,18,27,39,68–70].

Increasingly, researchers have been exploring the linking of RFID to BIM in construction for such things as resource management, logistics and supply chain management, process tracking, safety management,

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https://doi.org/10.1016/j.autcon.2018.05.023
Received 26 January 2018; Received in revised form 26 April 2018; Accepted 17 May 2018

and facility management [11,12,22,39,46]. In RFID-enabled BIM systems, real-time information visibility and traceability are improved; physical construction objects can be identified with their up-to-date information linked to the "as-built" BIM, which acts as the typical RFID system backend. The physical building process and the cyber BIM - in other words, the "cyber" and "physical" twins - are now connected to form a cyber-physical system (CPS); they can "talk" to each other. The benefits of both BIM and RFID can be better leveraged in combination than in isolation [8]; this becomes evident in numerous construction engineering and management (CEM) cases that have been reported in academic papers. However, its application so far in actual projects is still largely ad-hoc due to practitioners' limited understanding of it [8,53].

The gaps between industry needs and available academic research have been converted to the following research questions for the purposes of this paper:

(1) What are the current patterns and development trends of research linking RFID to BIM?

(2) How to help practitioners understand the diverse RFID-enabled BIM systems and make appropriate selections to suit real-life CEM needs?

In answering these two questions, an inclusive review of previous literature is conducted to revisit existing RFID-enabled systems from previous studies. This review also sheds light on how to select and deploy RFID-enabled systems according to various CEM needs. The aims of this study are therefore to: (1) identify the current patterns and development trends of linking RFID to BIM; and (2) develop guidelines for understanding and choosing appropriate RFID-enabled BIM systems for CEM activities. The rest of this paper is organized as follows. Section 2 first introduces a conceptual model for linking RFID to BIM to identify its main components, and then presents a thorough literature search to identify actual cases. Data extracted from these cases are analyzed in Section 3 by focusing on their status-quo pattern and development trajectory. Based on the analyzed patterns and evident trends, five-step guidelines are compiled in Section 4, and the implementation of guidelines is demonstrated in a real-life case of RFID-enabled BIM system application. Section 5 presents a conclusion to the study.

2. Research methods

2.1. A conceptual model

To help articulate the research aims and guide the research design, a conceptual model was proposed from the outset (see Fig. 1). The three interconnected components of the model, namely, a RFID system, BIM, and the information linkage, should be applicable to real-life CEM activities. The RFID system senses and identifies the useful properties (e.g., the ID or location) of an object (e.g., a building component or item of equipment) or personnel in various project phases [39]. BIM, both in 3D and 2D digital representation, can process (with its computation functions) and visualize information (i.e., offering real-time information visibility and traceability) to support decision-making. The model can be imported to a cloud platform for remote access, or it can be used in a standalone manner [71]. The information linkage component refers to communication of information (i.e., the properties) between the RFID system and BIM, which can be bi-directional. The information collected by the RFID system can be used to update the original information contained in BIM. In the meantime, BIM can provide information to be synchronized in the RFID system.

The options of the RFID system, BIM, and information storage plan are clearly listed in Table 1. What is unclear is how they have been considered in relation to real-life CEM activities (involving various properties of different objects in various phases), and whether they can be developed into guidelines for linking RFID to BIM to support future CEM activities.

2.2. Literature search

Based on the conceptual model and following the PRISMA (preferred reporting items for systematic reviews and meta-analyses) protocols [44], a literature search was conducted. It started with Google Scholar on 29 November 2017 using the query combination '(RFID OR UWB OR NFC OR "smart card") (construction OR infrastructure OR building) BIM'. The query means that the target publications must have explicitly mentioned a technical RFID term, a construction term, and the term 'BIM'. Since the term BIM was not widely accepted until the year 2002 [19], this review surveyed literature published between 2002 and 2017. In addition, the search was further restricted to the English literature, excluding patents and law cases.

The search initially produced 2190 hits including journal and conference papers, books, dissertations, and reports. The titles and abstracts then were screened for suitability. The hits in research areas irrelevant to CEM, e.g., medicine and agriculture, and those not focusing on BIM and RFID, were excluded. The full texts of 264 papers passing the preliminary screening were then downloaded and further refined by the authors based on two criteria: (1) including RFID and BIM in actual CEM applications; and (2) an original contribution (not a review article) with sufficient technical details elaborated in the actual applications. A total of 41 publications, including 22 journal articles, 16 conference papers, 2 theses, and 1 technical report, were finally collected for analyses. The number of hits seems somewhat small in light of widespread promotion of RFID and BIM in the construction industry. However, the selected papers, together with the remaining 264 papers searched, form a very useful information base from which meaningful findings can be derived.

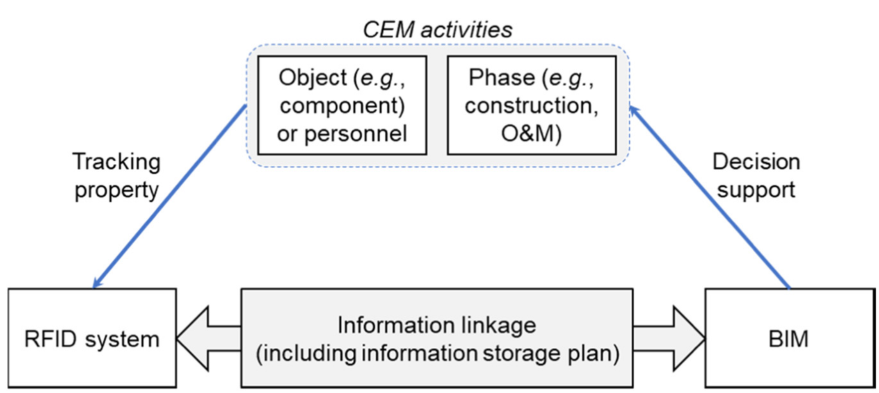

Fig. 1. Conceptual model linking RFID to BIM for CEM activities.