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Opportunities for enhanced lean construction management using Internet of Things standards

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ABSTRACT

Traditionally, production control on construction sites has been challenging, and still remains challenging. The ad-hoc production control methods that are usually used, most of which are informal, foster uncertainty that prevents smooth production flow. Lean construction methods such as the Last Planner System have partially tackled this problem by involving site teams into the decision making process and having them report back to the production management system. However, such systems have relatively long "lookahead" planning cycles to respond to the dynamic production requirements of construction, where daily, if not hourly control is needed. New solutions have been proposed such as *VisiLean*, *KanBIM*, etc., but again these types of construction management systems require the proximity and availability of computer devices to workers. Through this paper, the authors investigate how the communication framework underlying such construction management systems can be further improved so as to fully or partially automate various communication functions across the construction project lifecycle (e.g., to enable lean and close to real-time reporting of production control information). To this end, the present paper provides evidences of how the Internet of Things (IoT) and related standards can contribute to such an improvement. The paper then provides first insights – through various construction scenarios – into how the proposed communication framework can be beneficial for various actors and core business perspectives, from lean construction management to the management of the entire building lifecycle.

1. Introduction

Production can be conceptualized in three complementary ways: Transformation, Flow and Value (TFV) [1–3]. In traditional production management, the flow aspect has often been neglected, and particularly the information flow that is quite important from a lean construction management perspective since it affects all other resource flows significantly [3,4]. In the Last Planner® process of production planning [5], the site team needs accurate resource information about the construction tasks in order to effectively conduct lookahead and weekly planning activities. In this regard, Caldas et al. [6] mention that in a fragmented and dynamic environment, the integration and exchange of information between various organizational information systems and sources is crucial for efficient production management. However, as the construction industry is a project-based industry, such information often lies in disparate systems that are not always available to the site team, or even interoperable with one another, which is a major hurdle to reach such efficiency [7–9]. Traditionally, the problem of disintegration has been addressed by explicit one-to-one connections between information systems with the recent trends of implementing Enterprise wide Resource Planning (ERP) systems [10–12]. ERP systems often require significant development work for each connection; in most cases they do not extend to site-based processes [13]; and being time and cost consuming such connections are seldom created. To compound this, most construction projects have to work with manual processes and traditional methods of communication such as phone calls, faxes and emails [14,15], and even though this problem has been discussed extensively over the last two decades, the issue still remains unsolved. Arguably, there is a clear gap in the literature regarding communication frameworks that comprehensively address information flow requirements spanning across the construction project lifecycle, especially with a view to manage production related information.

Through this paper, the authors propose a communication framework that makes it possible to leverage system–system, system–human and human–system communication to fully or partially automate various communication functions across the supply chain and construction project lifecycle. The objective of the paper is thus twofold: first, considering the initial communication framework of current construction management systems such as the *VisiLean* system [16], secondly the paper investigates the main opportunities and challenges in extending this framework by integrating standardized IoT communication interfaces to "push" and "pull" the right (production) information

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to the right people and systems. Taking into consideration IoT technologies and standards becomes important in view of the rapid evolution and current impact that the IoT has in all sectors, including the construction sector [17,18]. According to a recent study of IDC (October 2014) about "Forecasting the Future of the Internet of Things in Europe", the number of the Installed Base of Connected Devices will pass from 9.1 Billion in 2013 to 28.1 Billion in 2020 representing 17.5% of CAGR (compound annual growth rate), and the corresponding Global Revenue Forecast of IoT businesses will pass from $1.9 Trillion in 2013 to $7.1 Trillion in 2020. The second objective is to deliver first scenarios and related benefits of using IoT standards as communication layer of *VisiLean*, or any similar system.

The paper is structured as follows: Section 2 presents the research methodology and underlying hypotheses. Section 3 defines the importance of production and information management in lean construction and gives insight into the main information streams to be tracked and controlled from head office, to site office, up to the field. Section 4 investigates how *VisiLean* can be used based upon the adopted IoT standard by highlighting the main benefits and challenges. First proofs-of-concept of this lean construction management system (i.e., *VisiLean* relying on the adopted IoT standard) are presented in Section 5 through several construction scenarios; discussions and conclusions follow.

2. Research methodology and hypothesis

It is hypothesized that the ubiquitous nature of IoT communication standards will improve the efficiency of information flow over the lifecycle of a construction project. The research is methodically aligned with the design science method [19,20], where the process begins by selection of a real-life problem (in this study, from the construction project lifecycle). It is followed by a thorough review of the problem area, i.e., application of information management tools to manage information flow in construction management. A framework for lean production system and project lifecycle management incorporating new communications standards is then developed. Based on the proposed framework, a prototype and use case scenarios are described, providing proofs-of-concept. The further stages of the design science method (i.e., evaluation of the framework in real-life use cases) and contribution to theory are not treated within the scope of this paper, they will be covered in subsequent publications through prototypes, and further piloted construction projects.

Before beginning to discuss the production and information management from lean perspective, it is appropriate to provide a basic definition of the key concepts used throughout the paper, namely:

- Lean Construction: refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System (TPS) to construction. As in TPS, the focus is on reduction in waste, increase in value to the customer, and continuous improvement;
- Last Planner System (LPS): collaborative planning and scheduling system developed by Ballard, (2000). The system provides a detailed production planning and control workflow that tackles variability and "flow" aspects in the construction management and involves the operatives in the field in the planning process;
- Lean Construction Management System: refers to any software-based construction management that supports the lean construction management workflows, and particularly LPS. Such examples can be found in VisiLean [21], KanBIM [4] and LEWIS [22] in the research arena, or still OurPlan[1] in the industry arena.

3. Production and information management in lean construction

In Fig. 1, an overview of workflow control on construction projects from a lean perspective is given by Howell and Ballard [23] who argue

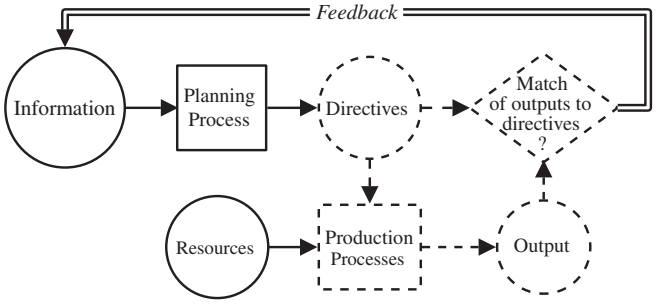

Fig. 1. Relationships between planning and control [23].

that the planning function provides directions to the governing execution processes, while controls provide measurement of conformance to directives along with inputs for future planning. From this vision, two types of information flows play a crucial role in construction management, namely information flows needed to efficiently carry out long-, medium- and short-term planning tasks (flow represented by bold frames and arrows in 1), and information flows needed to efficiently execute and control production in the field (flow represented by dashed frames and arrows). Accurate and timely information availability throughout the construction project, and even beyond (i.e., use and disposal phases of the facility), is a necessary condition to optimally plan and schedule the construction tasks.

Within this context, Section 3.1 provides a general discussion on information flow and task management in production, their importance, and the main issues that remain to be solved. Section 3.2 focuses on existing construction management systems that aim to address such issues. On the basis of the opportunities and challenges as discussed in the literature, Section 3.3 gives a concise view of the paper objective.

3.1. Information flows for production

Within the Last Planner System (LPS), "resource flows" and "tasks" have to be considered parallelly because the realization of tasks heavily depends on resource flows, and the progress of resource flows in turn is dependent on the realization of tasks [24]. One of the key functions of LPS is the "make ready" process that is part of the medium term planning (often called lookahead planning), where constraints to each task are identified (constraints refer to all those activities/inputs and resource flows that are required to complete a task) [24] and responsibility to remove them is assigned to task leaders (foremen, site supervisors, etc.). Researchers have discussed the importance of lookahead planning, and more particularly its role in successfully delivering construction projects (mainly due to reduced variability and improved workflow) [25–27]. It has also been argued that lookahead planning is one of the most difficult aspects to implement from the LPS [28]. One of the reasons for this is that on traditional construction projects where no software-based systems are used, there is currently no mechanism to track or anticipate the impact of identified constraints on workflow reliability before the execution week, or even until the Percent Plan Complete[2] is measured [30]. Researchers have put forward proposals to tackle the constraint or resource management on construction projects by providing site specific interfaces, e.g., with LEWIS [22] or KanBIM [4]. However, these systems rely on data input provided by workers in the field, and do not necessarily extend the service to external partners in the supply chain such as subcontractors or suppliers. Additionally, the tracking of constraints availability (i.e., prerequisite resources) is quite hard as the information related to their current status is not aggregated or synchronized by any function or system [3].

[1] http://our-plan.com/about-pagehttp://our-plan.com/about-page.

[2] Percent Plan Complete helps to improve the workflow and process reliability by constantly (weekly) calculating the percentage of plan reliability and making it visible and transparent across the whole team [29].