Chapter 6
Cyber-Physical Systems Framework for Smart Built-Environments

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ABSTRACT

Cyber-physical systems (CPS) can be seen as digitally-driven technological fusions of physical, spatial and virtual models. Thereby, the construction entities, locations and processes are tightly linked to the digital building models (BIM) using automated data capturing (ADC) solutions. This chapter focuses on the challenge of modelling a cyber–physical systems approach for constructing domains in order to effectively exploit the computation, control and communication capabilities. Pairing BIM and ADC technologies offers an adequate solution bridging the information gaps and promoting the collaboration among digital, spatial and physical construction entities. The results are cyber-physical objects (CPOs) at a level of "smartness" that provides enhancement of digital capabilities and the ability of context-awareness. These hybrid objects of digital equivalents and physical entities can be embedded in the construction and logistics processes in order to track progress and monitor the construction site activities and control flow close to real-time.

INTRODUCTION

Investigation of a digitally-driven production strategy is important to enable bridging the information gaps between physical construction and the digital models based on sensing and emerging technologies. A breakthrough has been achieved using Building Information Modelling (BIM) technology that can extrapolate into a digital fabrication strategy. Nevertheless, the granularity of the relationships and the interconnectivity between the digital models and physical fields has to be carefully examined in order to establish a cyber-physical coordination and integration in the construction.

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Cyber-Physical Systems (CPS) can provide for tight interaction between the physical objects and the virtual "cyber" models. Current Automated Data Capture (ADC) and BIM technologies are at a level of maturity that facilitates the integration of physical construction of spaces and objects into virtual information models which allows a bi-directional data flow in a near real-time. A cyber-physical system is about the conjunction between the physical world of things and the digital "cyber" world of software and computing. Like other industry 4.0 initiatives, a CPS approach can be seen as promising paradigms for a digitally driven technological fusion. Thereby the construction entities and site processes can be interrelated and linked directly to the digital building models using advanced ADC, i.e. QR-codes, RFID, GPS, RTLs, laser scanning, etc.

This work describes a CPS framework to close the information loop between the digital models and the real physical objects on-site by providing "near" real-time feedbacks about the actual state of physical things and their related activities.

This chapter focuses on design a cyber–physical approach in construction domain. A definition of CPS, state-of-the-art are reviewed. The current data flow problems between physical and virtual models on-site due to traditional data handling is briefly discussed. Next the chapter presents the importance, impacts and barriers of modelling a CPS for construction.

A generic framework enables the integration of physical construction entities with cyber models is addressed. The work introduces the CPOs as a basic unit in the CPS framework in order to have a complete digital footprint of the construction entities the during project lifetime. A digital construction site approach is developed to recognize the CPOs and maintain consistent relationships among the spatial, virtual and physical of construction.

A scenario for modelling of the CPOs based on object-oriented approach is developed in order to ensure a timely update in objects' status. Finally, the work proposes an approach for embedding these situational-aware objects in construction process models to support tracking activities and facilitate process monitoring and control close to real-time.

BACKGROUND

The rapidly progressing in ICT and sensing technologies open up the opportunity to achieve a bi-directional coordination and integration between virtual information models and physical construction in real-time. These functionalities have been introduced as features of the recent appearing of the CPS term, which is about the intersection of the physical and the cyber world (Lee, 2015).

CPS was originally developed in computer science as the next wave of innovation in ICT enabling the new generation of "smart systems". It has drawn great attention to academia, governments and industries due to its environmental and economic impact (NIST, 2013a). Beyond the embedded system, CPS is open, capable of multi-scale and designed as a network of interactive components more than standalone devices (Talcott, 2008; Lai, Ma, Chang, Chao, & Huang, 2011). Such smart systems encompass computing (virtual space) and physical components, seamlessly integrated and closely interacting to sense the changing state of the real world (NIST, 2013b). While CPS is still in its infancy, there are a few design principles, system architectures and prototypes -mainly in scientific works- for different application domains such as manufacturing, energy, transportation and civil infrastructure and medical systems (Sanislav & Miclea, 2012).