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ScienceDirect

Energy Procedia 96 (2016) 212 – 217

Energy Procedia

SBE16 Tallinn and Helsinki Conference; Build Green and Renovate Deep, 5-7 October 2016, Tallinn and Helsinki

Integrated design in case of digital fabricated buildings

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Abstract

The importance of the detailed BIM for buildings like the free-form building in our case cannot be emphasized enough in case of automated and especially additive manufacturing. Integral design of all building accessories like internal heating, ventilation, and air conditioning (HVAC), water supply, and drainage network installations is essential when applying additive manufacturing. In such a building it is impossible to build the ventilation network with traditional vertical and horizontal canals. Important benefit of digitally fabricated building can be internal topological optimization of building elements like walls and slabs for thermal insulation and structural capabilities. Application of large-scale additive manufacturing systems in the AECO industry is in early research phase. Future research directions are further parameterization of the interoperability demand function, BIM maturity, automation of workflow models, and new approaches for engineering of embedded building elements.

Peer-review under responsibility of the organizing committee of the SBE16 Tallinn and Helsinki Conference.

Keywords: AECOO; digital manufacturing; data interoperability; BIM; 3D-printing

1. Introduction

New service-oriented manufacturing paradigm, cloud manufacturing (CMfg) [1], is a vibrant research topic, which requires: (a) business collaboration culture [2], (b) sharing of resources thru the interoperability and standardisation within product lifecycles ([3], [4]) and (c) automation of manufacturing workflows [3]. In the AECOO industry, interoperability was regarded as the driving force behind efforts for improved productivity [5], [6]. It is widely believed that the establishment of interoperability of the information systems between project stakeholders can generate significant business value and enable profitable growth [7], if the AEC industry would minimise cost of interoperability inefficiency [8] between stakeholders in the construction processes.

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Peer-review under responsibility of the organizing committee of the SBE16 Tallinn and Helsinki Conference.
doi:10.1016/j.egypro.2016.09.125

Therefore, interoperability in the construction industry improves construction labour productivity thru diminishing duplication of effort and reducing the chance of on-site mistakes, which in consequence, saves time. The negative cost impact increases with advancing life-cycle phase, from planning and design phase (17%) to construction phase (26%) and to operation and maintenance phase (57%).

2. Interoperability for service-oriented manufacturing

The cost share of interoperability inefficiency in construction lifecycle is the highest in the operation and maintenance phase. This means that the phase has the greatest potential for interoperability improvement when we compare it to the cost share in the planning and design phase, and construction phase. Improved interoperability in the operation and maintenance phase would reduce the cost share in this phase.

Automated manufacturing systems correspond to the construction phase (erection of the building) [9]. More automation in construction phase would increase interoperability demand in this phase.

Although the interoperability problem in construction implies not only connecting information systems but also business processes, culture and values, and management of contractual issue [10], focus of our research intends to contribute to the understanding of technical interoperability problems related to the automated manufacturing. To identify the interoperability problems, we conducted an experiment that included: (a) digital design of a reinforced construction element with integrated central ventilation duct system, (b) preparation of tasks for automated manufacturing of the element, and (c) manufacturing of the element with the additive manufacturing (AM) technology (3D printing) [11]. The problems that we identified are: (a) exchange of digital parameterised workflow model is not supported in IFC2x4, (b) streamlined generation of tasks for automated manufacturing systems from BIM is not supported.

In the following part of the section we derive the main requirements for more interoperable use of automated manufacturing systems in the construction phase. The requirements are supported by an experiment where the laboratory size construction element model was manufactured in a fully automated manner with the AM 3D printing technology. The element demonstrates a non-traditional design and embedded building accessory (ventilation canals). Our goal was twofold: (a) to identify all interoperability problems in the process from design to automated manufacturing of the model, and (b) to identify requirements for application of structural engineering result, such as reactions and internal forces, into the infill strategies. The identified problems are then analysed and improvement proposals presented as requirements for future projects.

3. Computer-controllable lifecycle workflow model

Traditional and deep-rooted construction scheduling practice patterns deny the need for digital workflow model, which would enable stakeholders (investors, project managers, contractors, subcontractors, cost estimators) better control over the construction process. A digital parameterised workflow model is needed for future BIM maturity Level 3 (4D, 5D and 6D).

Today, construction workflow modelling is understood as construction scheduling task only. Construction scheduling consumes data from the mostly manual quantity take-off and cost-estimating task. In a fully integrated and collaborative process the construction scheduling task would consume design model and (a) trigger preparation of quantities and costs for materials, parts, labour and machinery (including automated manufacturing systems), (b) optimise scheduled tasks (activity id, activity name, preceding activities, succeeding activities, activity duration, activity cost) in a way to achieve minimal Project Completion Time (PCT) and/or Project Completion Cost (PCC), and (c) update single shared BIM with results from (a) and (b). These data, for example material and quantities, can be used for preparation of tasks for automated manufacturing systems.

In order to achieve more controllable construction workflow, traditional Corporate Performance Management (CPM) based software, for example MS Project, Primavera, Suretrack and ProjectLibre, must interface to already existing standard business process management models like Business Process Modelling Notation (BPMN) [12]. Traditionally, construction schedule created with CPM software is digitally communicated in proprietary format