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Supply-chain transparency within industrialized construction projects

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ABSTRACT

This paper addresses those issues relating to the integration of information flows in relation to material management throughout the construction industry supply-chain. Based on a case study, it shows how to bridge any gaps between those information systems used within the design, prefabrication, and on-site construction processes.

The information requirements of the aforementioned three key processes are analysed regarding an industrialized construction project, and any gaps identified between their three sets of requirements. A theoretical model for information mapping is proposed using these requirements. The solution is then verified through a case study, performed within the operational environment of a construction company. This case study represents one approach for applying the proposed information mapping model, and possible benefits for the industry.

The information analysis highlights significant distinctions among particular views on the information required for supporting the tasks during the three above-mentioned processes. The main difference lies in the levels of data granularity important for particular tasks. Building Information Modelling based construction (BIM-based construction) proved itself to be an adequate context for bridging the information gaps. BIM-based construction can accommodate the proposed model for information mapping across the processes. Within this context it is possible to separate the identities of physical building elements from those of designed building elements, which is required when mapping.

This study shows that it is feasible to automate the proposed information mapping in the form of a computer algorithm. It explains the value and necessity of building information model (BIM) usage, in order to provide the context for information mapping. The integration of design, manufacturing, and construction processes, and a transparency of information about material resources across these processes, would bring significant benefits for all stakeholders within the supply-chain. In the case study, the architecture and a prototype of the software system were developed in order to implement the proposed idea. Specifically, the case study showed that the proposed information mapping improved the project's progress monitoring, detailed planning, and management of material flows, across the construction supply-chain.

1. Introduction

Industrialization regarding construction started several years ago [1] and is an important trend within the construction industry. It aims to achieve several improvements within the sector, such as higher productivity levels and better quality construction products. Reports and case studies from different parts of the world have shown that prefabrication and on-site assembly are becoming common practices [2,3]. Industrialization regarding construction tries to address the problems of low profit-margins in comparison to other industries, and a shortage of skilled workers [4,5]. The prefabrication of building components at a remote facility is shown to save space for material storage on-site, assures better quality-control during the parts' production, reduces waste and enables re-engineering, and more efficient supply-chain management [3].

All of the above benefits are the result of industrialization partially shifting activities from a construction sites to remote locations. Therefore, industrialization of the construction process requires a higher level of integration among partners within a construction project, since the manpower, materials, and equipment within a project have to remain coordinated. This coordination is maintained by frequent exchanges of information. Within construction projects, this exchange takes place in the context of linkages between independent organizations. Such contexts require high level of interoperability among partners, which increasingly contributes to the success in current highly dynamic

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field of construction [6]. Co-ordination is especially important within the context of industrialized construction because many construction sites receive prefabricated building elements from the same manufacturer. Hence the production and supply of the building elements must fit into the overall project schedule at each construction site. Actually, a prefabrication manufacturer works within a multi-project environment. At the same time, we have to take into account that companies engaged in prefabrication usually produce products in 'make-to-order' standard and configurable products [7]. Love identifies [8] that construction projects are increasingly performed as concurrent processes and, therefore, require strong information coordination and integration amongst the partners. The impact of such coordination on project effectiveness is identified. Information from the supply-chain management system could significantly improve the detailed planning of prefabrication and on-site activities. Since the manufacturers have to deliver building elements to several sites, the production process and logistics should be aligned with the construction site schedules. In regard to 'last planner' principles, information-flow integration between partners within the construction supply-chain, significantly improves any overseeing of 'what can be done' compared to 'what should be done' [8]. In a similar manner, research in the fields of enterprise resource planning (ERP) and supply-chain management (SCM) show that the integration of many isolated systems, modules, and strategies for effective planning, control and the execution of large projects across both manufacturing and distribution environments significantly improves planning, control and execution in comparison to interfaced or loosely-integrated systems [9]. In addition to the planning of on-site activities, information technologies significantly help to distribute changes in those designs that occur during the later project stages among several partners throughout the supply-chain, who are affected by the change [10].

However, with regard to information flows within partner organisations and between project partners, the construction industry still faces many problems. As described in [11], to achieve interoperability among the systems, information must be physically exchanged, must be understood and also conceptual and organisational interoperability must be reached. Construction companies as well as other types of organizations that try to implement ERP systems are confronted with very high complexity of the task [12]. This paper focuses on a particular problem identified when working with construction companies and which was also clearly pointed out by [2]. Information technologies and those tools used to support tasks within a construction project, such as computer-aided design (CAD) tools, are unsuitable for integration within those enterprise resource planning systems that support manufacturing processes. Also certain systems developed for manufacturing possess insufficient abilities for supporting construction tasks such as structural design and detailing. Presented research focused on bridging the gap between data structures relating to a building from the perspectives of design, detailing, and on-site work, and those data structures used during enterprise resource planning (ERP) for supporting the prefabrication of construction elements used for the actual erection of the building. The goal was to bridge the gap between these two specific semantic views regarding the building, with the aim of establishing better integration among partners within the construction supply-chain.

In order to achieve this goal, the presented work was structured into tasks which included: analysis of work processes; synthesis of common information needs for building design processes, prefabrication processes and construction-site processes; and the development of those data transformations needed to overcome the gaps identified within the flow of information. A use-case was designed and implemented to serve as proof of the concept, which demonstrated the appropriateness of the transformations.

2. Work process analysis

The processes across the construction project supply-chain were analysed as the first step of this work. It should be pointed out that the processes described here are actually performed by the same business entity. However, a company plays only one of the described roles within a particular project but is interconnected with other parties responsible for other roles. Within other projects these companies may perform different roles. This case study directly reflected the situation referenced by Segerstedt and Olofsson [13], where the construction company is often flexible within its supply chain. It can be positioned as a supplier on one tier of the supply chain for a certain project but on another tier for other projects. Hence, the results and principles discussed in this paper are applicable to the whole supply chain of a construction project, despite the fact that its analysis was always performed within the same company.

The company providing the environment for the analysis is involved in projects as a supplier of prefabricated building elements and also as a contractor responsible for detailed design and construction. The company is large sized and is involved in several projects both within Slovenia and abroad. Primarily it produces storage-house buildings, industrial halls, and large storage facilities. These buildings consist of load-bearing steel or concrete structures, and are enclosed with metal roofs and façade elements. In addition to their construction projects, the company also manufactures roof and façade elements for the general market. The scope of the presented work and the case study was centred on these types of buildings and related processes. From a time perspective, the scope of this research targeted those project workflows that start after the project contract has been signed and continue until the end of the construction phase.

The work processes at the company can be divided into three groups of activities—(1) detailed design, (2) prefabrication and (3) construction site activities. *Detailed design* inputs customers' requirements and architectural design, and has two outputs. It is the basis for the manufacturing of prefabricated building elements whilst also producing blueprints for the construction. The work is well supported by computer-aided design tools (CAD) for both the load-bearing construction and façade elements' designs. *Prefabrication* is organized as a mass-production, and is highly automated. The industrialized production of building elements is integrated within other business activities such as sales, purchasing, and logistics via the Enterprise Resource Planning (ERP) system. *Construction site activities* are projected in relation to and including the organization of the construction site, construction work, project progress monitoring and management activities, and the tracking of material flows to and on the construction sites. The analysis showed that this group of activities is insufficiently supported by software tools. Detailed planning and data collection concerning the performed construction work were handled inconsistently, using software tools selected individually by a particular project manager. The project managers often used spreadsheets for the planning and tracking of activities, yet sometimes used project management tools such as MS Project, and even performed in a more relaxed manner using text editors. Note-taking and reporting were implemented by the use of text editors, emails, phone calls, or even just written on paper. In addition, the structure and scope of the documentation varied across the projects. The consequence of these inconsistencies resulted in difficulties when trying to synchronise activities across the above-mentioned groups.

The synchronisation and close coordination of all three activity groups is necessary, especially because the prefabrication and