DEVELOPMENT OF SYSTEMATIC CONSTRUCTION LOGISTICS USING 'INTELLIGENT PRODUCTS'

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Abstract: A cost-effective transfer of materials and tools from supplier location to construction site along with efficient information flow is defined as systematic construction logistics. Development of appropriate IT mechanisms plays an essential role for simplified production planning and elimination of wastes from broken resource. The contribution of this study in construction supply chain is to design and develop an innovative logistics management framework using context-aware and autonomous product centric system. More specifically, the proposed framework is responsive to real-world circumstances by demonstration of autonomous behaviour, and support several lean principles to improve resource and information flows. This paper addresses (i) an innovative solution for overcoming the construction logistics information flow challenges based on the intelligent product concept, (ii) a requirement analysis phase using "Quality Function Deployment" to turn the product requirements into technical specifications and (iii) implementation of a logistics management framework prototype to develop a first proof-of-concept.

Keywords: Lean construction, computing, mixed reality, template, instructions.

1 INTRODUCTION

Construction logistics is a set of activities, including strategic management of procurement, delivery, storage of parts and materials as well as relevant information flows through different agents. Efficient construction logistics maximizes the current and future profit using effective fulfilment of the requirements (Wegelius-Lehtonen, 2001). On the other hand, several studies pointed out problems related to inefficient materials handling, inappropriate delivery schedule and shortcomings of interactions between suppliers and clients due to highly fragmented supply chain (Ying et al., Agapiou et al., 1998; Dave et al., 2015). In the same vein, another study pinpointed important reasons of on-site inefficiencies, which caused problems in decision making on buffers, off-site production and delivery planning (Azambuja and O`brian, 2009).

The literature on construction as an assembly operation emphasizes the vital role of efficient information sharing in the supply chain (Koskela, 1999; London and Kenley, 2001; Shakantuet al., 2003). One potential for resolving the significant problems of the construction supply chain is to introduce 'intelligent products' into the information management system (Dave et al., 2015). Utilizing intelligent products, the sequence and control logic of the production can be attached to individual construction assemblies and components from the design phase. The authors of this paper propose a technical and practical solution which enables the construction components to carry life cycle

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information from their inception to construction and maintenance. To this end, this paper is continued by a review of existing problems through current approaches of logistics management. The next section discusses the proposed solution and the major high level enabling technologies. In the fourth section, a requirement analysis using QFD is performed in order to translate system functional requirements into technical specifications for the implementation of a logistics management system. Finally, the method and materials for the prototype are then explained after which conclusions are drawn.

2 CURRENT APPROACHES IN CONSTRUCTION LOGISTICS

Logistics management essentially is recognized as the management of both information and materials flows through supply chain with a high level of customer satisfaction. A potential reason for ineffective logistics management is the fragmented nature of the construction industry logistics and challenges in data integration and compilation (Sargent, 1991). In traditional construction practice, there was an information gap between resource management and workflow (Arbulu et al., 2005). Subsequently, the planning team organized all schedules related to operations, workers and tools with the assumption that all facilities and materials for installation are available.

A study by Jang et al (2003) noted the importance of five main parameters on project managers` satisfaction of construction logistics such as contractor`s organization, material and information flow. Moreover, this study highlighted the necessity of construction logistics software and technical improvement. Last Planner System (LPS) developed by Ballard (2000) partially tackled the variability and "flow" aspects of construction problems by providing a detailed construction planning and control workflow. However, Dave et al, (2015) pointed out that such systems have relatively long "look-ahead" responsive planning to construction requirements where daily or even hourly control is needed.

Product tracking technologies such as radio frequency identification (RFID), global positioning system (GPS) and ultra-wideband have been applied in construction logistics. However, implementation of such technologies has been deployed in the limited levels (Young *et al.*, 2011) and implementation of integrated technologies within construction supply networks is still needed. Present logistics management systems with localized information system are capable to serve a specific amount of requirements. Nevertheless, they are not adequate due to requested changes and updates in design and manufacturing which can result in incorrect specifications and receipt of wrong components on site (Cutting-Decelle *et al.*, 2007). In the next section, a potential solution will be proposed which can help to overcome the aforementioned gaps in construction logistics management.

3 POTENTIAL SOLUTION – LOGISTICS BASED ON PRODUCT CENTRIC CONTROL

Nowadays, products with unique identification and integrated control instructions are being developed for simplification of seamless information flow, material handling and customization throughout the supply chain (Kärkkäinen & Holmström, 2002). Dave et al. (2015) noted that intelligent products have contextual operative logic linked within individual components already from design phase and they are able to support whole lifecycle from design to construction and maintenance. The derived advantages of

intelligent products such as autonomous behaviour and responsiveness to real-world circumstances can considerably reduce the need for planning and organization, improve inventory management and finally improve product quality and project performance (Musa *et al.*, 2014).

The basic principle of product centric control is to embed the products and process related information, which is necessary for construction project actors' communication across supply chain, within products themselves. Consequently, the individual component and assemblies within intelligent product are capable to carry the required sequence and instruction of construction project with themselves from design phase along the entire lifecycle. In other words, the intelligent construction components should be aware of the next operation schedules. Therefore, a construction product itself would request a delivery service from the supplier or manufacturer whenever it is ready to be delivered to the construction site. As the product is shipped to the site, it should provide the information about its location in inventory site and then inform the specific worker to install the product based on planned time schedule. From the logistics point of view, such scenario is completely implementable using the intelligent products capabilities in the information flow between different project agents. To this end, it should be investigated what technologies are required for implementation of intelligent products.

Internet of Things (IoT), Building Information Modelling (BIM) and Lean construction techniques are the main enabling technologies for implementation of intelligent products (Dave *et al.*, 2015). Through IoT communication framework, an infrastructure where the product`s information can be exchanged between organizational agents and individual products is provided. BIM plays a vital role in the reduction of planning redundancy and raising engineering efficiency with capability of storing virtual and multidisciplinary information about products (Said & El-Rayes, 2014). Lean construction is considered as the alignment and holistic following of simultaneous and continuous improvement in all dimensions of construction stages (Abdelhamid & Salem, 2005). Systematic logistics system based on intelligent products operates on lean construction technique such as "pull" based production to maximize value across supply chain and reduce waste from lifecycle stages by providing materials in construction site when and only when it is needed.

4 MATERIALS AND METHODS FOR DEVELOPMENT PHASE

The aim of this research is to develop a framework for a 'logistics management system utilizing intelligent products' to track individual materials and components from their inception, assembly and installation across construction stages. In the previous section, some of the main enabling technologies were discussed. In this section, the materials, tools and methodologies for such development are investigated to better understanding of the technological and scientific perspectives of the proposed solution.

4.1 QUALITY FUNCTION DEPLOYMENT

During an efficient product design, a designer or design team should identify the end-user expectations accurately. Quality Function Deployment (QFD) is a systematic approach to identify customer requirements for design a product or service considering all stakeholders involved in the production and supply chain process (Esan *et al.*, 2013). The QFD approach taken in this research is adapted from (Kubler *et al.*, 2010) and contains two levels of matrix evaluation namely "house of quality" in order to translate high-level requirements into scientific and technological specifications as indicated in Figure 1.
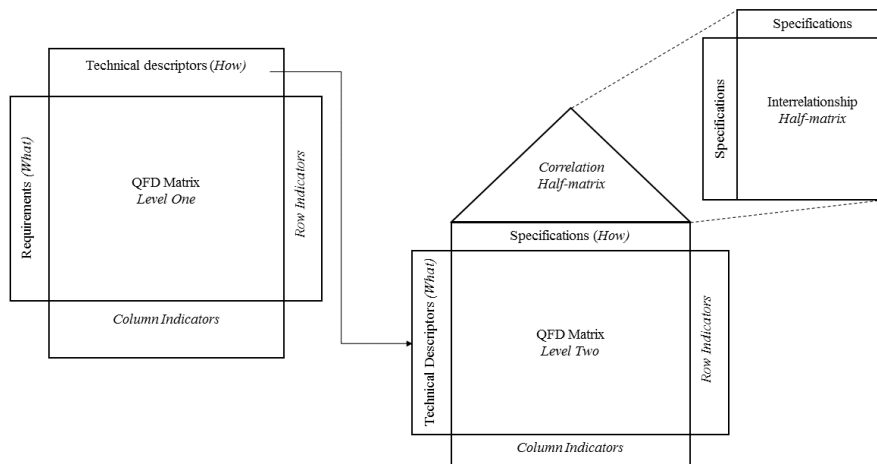
Figure 1: Two level QFD matrices (House of Quality)

A functional analysis is performed to extract product requirements by investigating existing literature such as (Dave *et al.*, 2015; Said & El-Rayes, 2013; Said & El-Rayes, 2014) and interviewing Aalto Bim Lab[4] researchers. Subsequently, the extracted and prioritized requirements by AHP (Analytic Hierarchy Process) method   are prepared for QFD input. Moreover, the QFD weights are assessed and consensed among the Aalto BIM Lab researchers especially the authors of this paper. However, it is intended to collect the real customer requirements from the industry partner`s key personnel in further studies.

In level one, the collected requirements (What) are listed in rows with their initial priorities using AHP method (from low priority 1 to high priority 5) and technical descriptors (How) are placed in the columns of this matrix. The relationship matrix is developed then between What-How, as shown in Figure 2. The column indicators of matrix present the information about the relative influence of a single technical descriptor on all requirements and row indicators shows the relative effects of technical descriptors on single requirements.
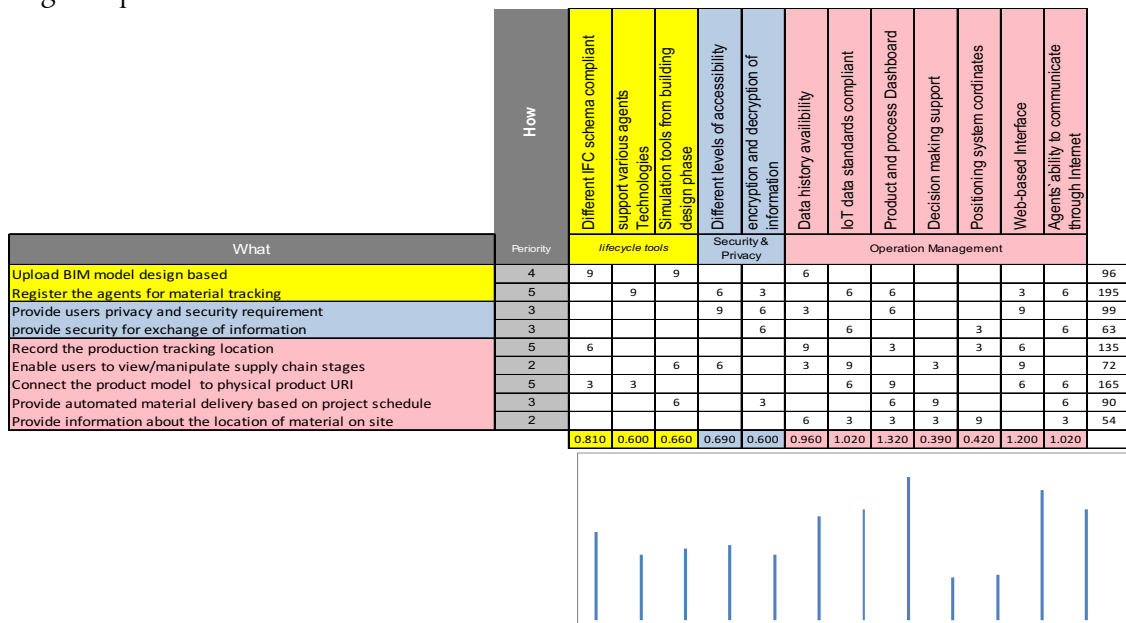
What	Periority	Different IFC schema compliant	support various agents Technologies	Simulation tools from building design phase	Different levels of accessibility	encryption and decryption of information	Data history availibility	IoT data standards compliant	Product and process Dashboard	Decision making support	Positioning system cordinates	Web-based Interface	Agents' ability to communicate through Internet	
		lifecycle tools			Security & Privacy		Operation Management							
Upload BIM model design based	4	9		9			6							96
Register the agents for material tracking	5		9		6	3		6	6			3	6	195
Provide users privacy and security requirement	3				9	6	3		6			9		99
provide security for exchange of information	3					6		6			3		6	63
Record the production tracking location	5	6					9		3		3	6		135
Enable users to view/manipulate supply chain stages	2			6	6		3	9		3		9		72
Connect the product model to physical product URI	5	3	3				6	9			6	6		165
Provide automated material delivery based on project schedule	3			6		3		6	9			6		90
Provide information about the location of material on site	2						6	3	3	3	9		3	54
		0.810	0.600	0.660	0.690	0.600	0.960	1.020	1.320	0.390	0.420	1.200	1.020	

Figure 2: First level of QFD matrix

Through second level of QFD, the previous approach should be reiterated between the technical descriptors (How) of first matrix and specifications of logistics management system placed in columns. In this manner, the quality is ensured by constraints spreading since the technical descriptors of the first level matrix become the What for level two matrix as illustrated in Figure 3. The aim of interrelationship half-matrix development is to identify areas which some specifications can conflict with others and some of them can enforce other processes. The second level matrix is highlighting the technical specifications for functional requirements fulfilment. The results out of column indicators of second level matrix show that the specifications "Open IoT messaging communication framework", "3D Web technologies", "Distributed Architecture" and "IFC standard compliant" are respectively the most important. Consequently, a logistics management system prototype is developed in order to validate the pertinence of the achieved results from requirement analysis.
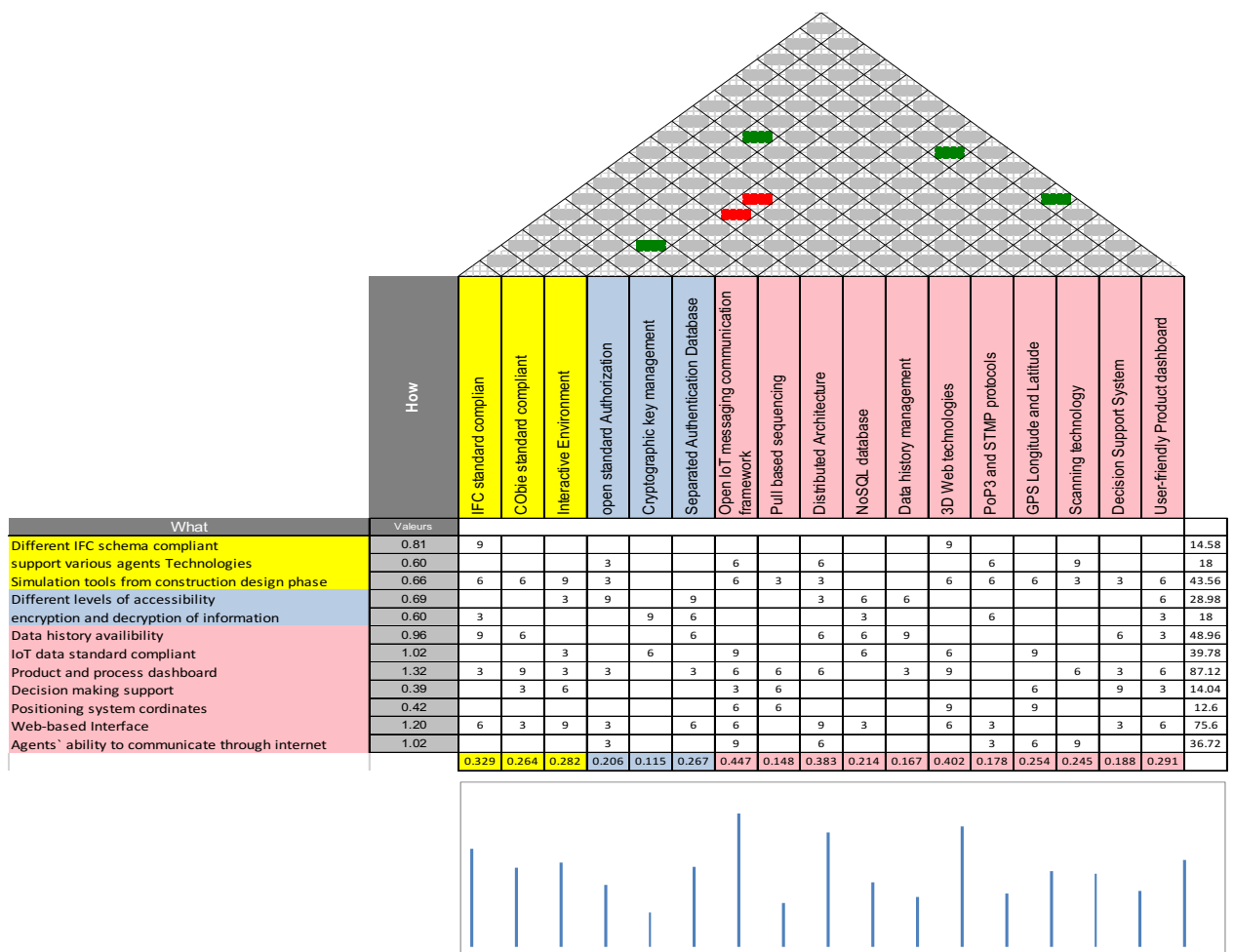
What	Valeurs	IFC standard complian	CObie standard compliant	Interactive Environment	open standard Authorization	Cryptographic key management	Separated Authentication Database	Open IoT messaging communication framework	Pull based sequencing	Distributed Architecture	NoSQL database	Data history management	3D Web technologies	PoP3 and STMP protocols	GPS Longitude and Latitude	Scanning technology	Decision Support System	User-friendly Product dashboard	
Different IFC schema compliant	0.81	9											9						14.58
support various agents Technologies	0.60			3				6		6				6		9			18
Simulation tools from construction design phase	0.66	6	6	9	3			6	3	3			6	6	6	3	3	6	43.56
Different levels of accessibility	0.69			3	9	9				3	6	6						6	28.98
encryption and decryption of information	0.60	3				9	6				3			6				3	18
Data history availibility	0.96	9	6					6		6	6	9					6	3	48.96
IoT data standard compliant	1.02			3		6		9			6		6			9			39.78
Product and process dashboard	1.32	3	9	3	3		3	6	6	6		3	9			6	3	6	87.12
Decision making support	0.39		3	6				3	6							6	9	3	14.04
Positioning system cordinates	0.42							6	6					9	9				12.6
Web-based Interface	1.20	6	3	9	3			6		9	3		6	3			3	6	75.6
Agents` ability to communicate through internet	1.02			3				9		6				3	6	9			36.72
		0.329	0.264	0.282	0.206	0.115	0.267	0.447	0.148	0.383	0.214	0.167	0.402	0.178	0.254	0.245	0.188	0.291	

Figure 3: Second level of QFD matrix

4.2   Implementation of prototype

To implement the prioritized technical specifications, agile software development is selected which can deliver the system prototype faster and more organized. A simple prototype scenario begins with assigning the IFC model URI to physical product through NFC writing from product inception. However NFC and RFID are different in term of communication technology and bandwidth, the identification can be performed because

of its ease of use and install at this stage of study. This action enables the products to carry the information about themselves through their lifecycle and a link is created between the IFC model and individual products.

The agents are responsible to provide traceability of products through their manufacturing, supply chain and installation. Moreover, the products are able themselves to activate actions such as "delivery requests" and "worker call" based on the BIM model design and communication protocols. A high-level architecture of overall system is then identified to facilitate better understanding of different modules of the system as depicted in Figure 4. Server consists of a web server, which is publicly accessible through the internet and communicates via HTTP protocol and messaging interfaces (O-MI and O-DF) with web client and agents. It also contains the "Authentication Interface" to control either the authentication of incoming requests and user permissions to access the services. Valid requests then can be handled by "Service Interface" to be provided with corresponding responses upon the type of request. The basic implementation of server is utilizing BIMServer (Beetz *et al.*, 2010), which is an open source software, in order to facilitate Parsing and storing IFC files in database.
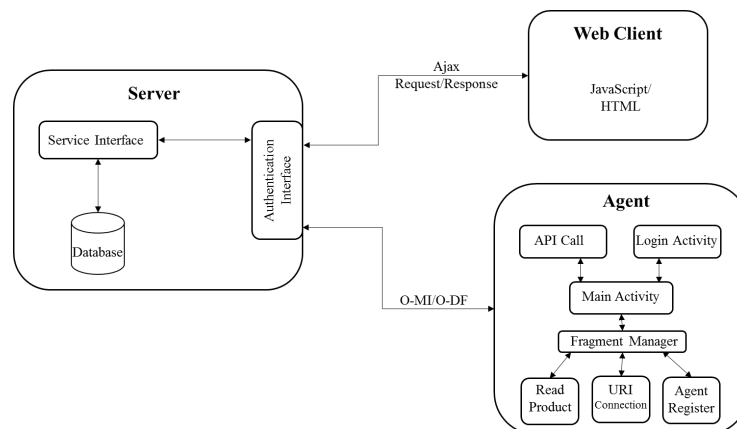
Figure 4. High level architecture of overall logistics management system

Web client is product and process dashboard developed for managers and end users to retrieve and manipulate all the information related to project plan and progress, product details and instructions for installation. The product dashboard within the web client contains all information about selected product in 3D model including product ID with all previously recorded and recent location information. In addition, all registered agents information such as ID and location are available in this part of the web client.

The objective of an agent is to transmit information i.e. location and ID between product and server. In this study, the agent is developed on Android OS with access to NFC device in order to ease the portability and hardware development limitations. The basic workflow of an agent can be summarized in agent registration, authentication, assignment of URI to products NFC and retrieving product information. From the technical viewpoint, agent consists of APIs to communicate to the server for handling the requests and User Interfaces which are handled by fragments. Figure 5 illustrates a few sketches from developed logistics management system prototype.
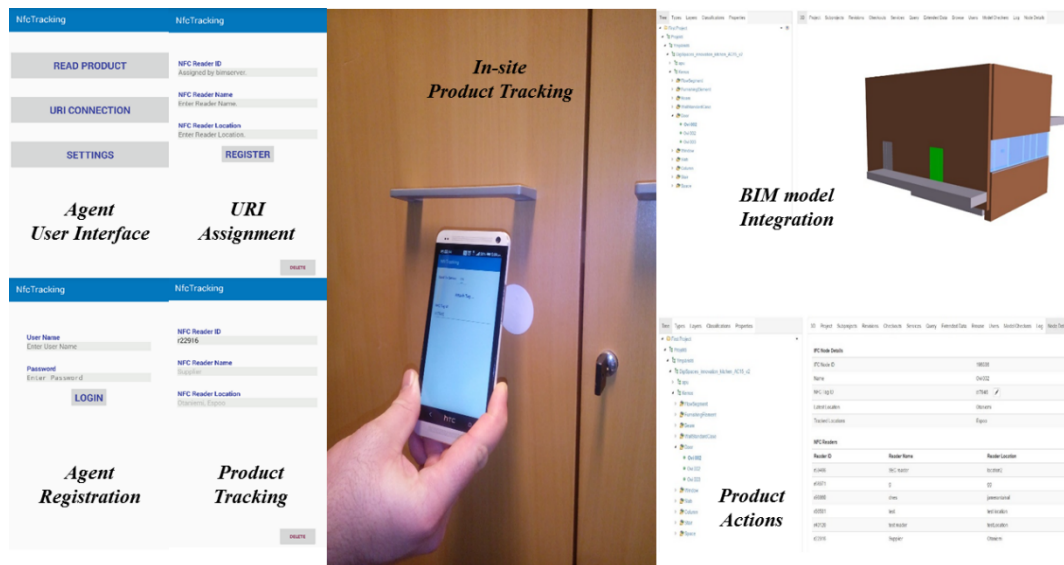
Figure 5: Logistics management system prototype sketches

5   CONCLUSIONS

The current approach of logistics management through construction supply chain has significant information flow problems which are rarely addressed in literature. Moreover, companies hesitate to invest in development of logistics management automation since they think that the added value cannot cover the budget for investment. There have been attempts to eliminate information gap across construction life cycle by providing heterogeneous solutions in individual areas of design management and production. However, the lack of integrated information system can be observed through entire construction projects. The developed solution based on intelligent product concept attempts to tackle the aforementioned problems by a detailed functional analysis to implement a system with a high level of acceptance. The system prototype was implemented according to the results of QFD method which prioritized the requirements and technical specifications of proposed solution. However, there is a need to implement all specifications of the system in further studies.

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