A Case Study: Conception of digitalizing prefabrication processes in the construction industry

Z. Cai[1], M.B. Tarfaoui[2], S. Kessler[3] and J. Fottner[4]

[1]School of Engineering and Design, Technical University of Munich, Germany
[2]Department of Informatics, Technical University of Munich, Germany
[3]School of Engineering and Design, Technical University of Munich, Germany
[4]School of Engineering and Design, Technical University of Munich, Germany

zhen.cai@tum.de, mohamed.tarfaoui@tum.de, stephan.kessler@tum.de, j.fottner@tum.de

Abstract -

During the last few years, the importance of prefabrication and its digitalization has grown significantly in the construction industry. In this context, a German construction company intended to extend an existing warehouse application into a system that additionally monitors production time to identify the bottleneck. In this case study, a concept of digitalizing the prefabrication was proposed with the components of hardware, middleware and software. In terms of hardware components, an RFID system was tested in the production plant and a feasibility study of a Bluetooth system was done. In the software concept, a new framework was designed and implemented with new functions, e.g. introducing a resolver layer to reduce controller workload. Based on this concept, the company is able to utilize data from both production and warehouse.

Keywords -

Prefabrication; Modular Housing; Digitalization; RFID; Bluetooth

1 Introduction

In the construction industry, prefabrication is widely recognized as an important method to enhance industrialization progress [1]. Prefabrication enables an off-site production of construction elements, from simple construction components to complex building modules [2]. Not only can the prefabrication improve the level of automation, but also reduce energy consumption and environmental pollution [3]. In this case study, the authors have cooperated with the German company maxmodul, which plays a leading role in the prefabricated house section with its solid construction.

In many manufacturing industries, the production processes are highly digitalized and automated by systems such as Manufacturing Execution System (MES) and Warehouse Management System (WMS) [4, 5]. In comparison, few construction companies have applied those systems in their prefabrication plants because of the lack of research and practical applications in the construction industry [6]. RIB iTwo MES [7] is one of the very few MES software in the construction industry but only supports limited processes. To overcome the gap, we propose in this paper a concept to digitalize the prefabrication processes based on a case study in company maxmodul. In the next section, we explain the current situation, and requirements from maxmodul, which leads to the designed concept. After that, both hardware and software are implemented and the test results are summarized. Finally, the results are evaluated and future work is proposed.

2 Initial Situation and User Requirements

2.1 Initial Situation

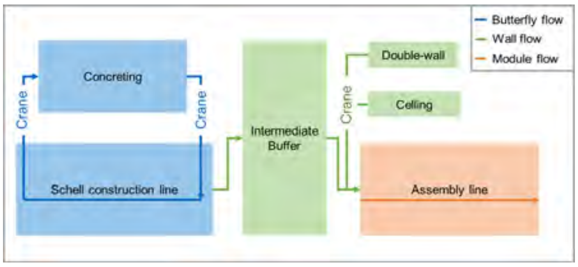

Figure 1. Material flow in the prefabrication plant maxmodul[8]

In the **production floor**, a material flow simulation was conducted by Fischer et al. [8]. The production follows the principle of mixed-model Assembly. The modular housing elements go firstly through the concreting stations and then enter the buffer areas, waiting for assembly. Two elements (double-wall and celling) are produced in separate stations and transported with cranes, as shown in Figure 1.

After the assembly line, the products (modules) are stored temporarily in an outdoor **block warehouse**. A portal crane is responsible for the transportation of modules.On the portal crane, an RFID reader and a GPS device are installed. On each module, an RFID tag with the module number is attached. The reader on the portal crane records the number of the module and the GPS data every time it changes the position of the modules. The data are displayed and stored in internally developed software, which has some technical flaws due to its outdated architecture.

2.2 User Requirements

After interviewing the users of maxmodul company, the most urgent requirements are selected as follows:

- Digitalizing the production time: as like in any mixed-model assembly, the bottleneck of the production in maxmodul shifts from one station to another depending on their production time. The digitalization of the production time is essential for the company to identify the bottleneck and take measures in early time to avoid production stops.
- Refactoring and extending the software: the main goal is to refactor the software to a stage with robustness and efficiency. In addition, the output of the system focuses on the graphical display of the database entries in both table form and on the maps. Also, the communication with the connected MySQL Database should be optimised.

3 System Architecture

Based on the interviews with six users (two production manager, three workers, one IT expert), a system architecture consisting of the following components is proposed, also shown in the Figure 2:

- Hardware components: the data reader and a gateway ensure the sending information from the physical system to the intranet/internet.
- Middleware: it is a centralised repository that collects data from various sources. It allows persistent data storage and fulfils complex data processing.
- Software components: it provides the users with different functionalities, such as monitoring and planning tools.

Within this architecture, different digitalization scenarios can be realized. However, the scope of implementation in the next chapter is limited to the hardware and software components, reflecting the user requirements.

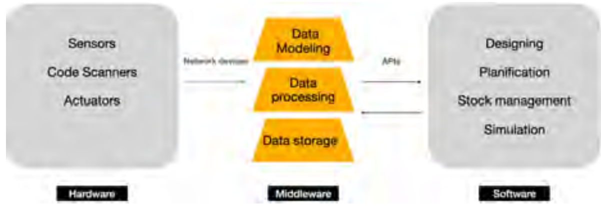

Figure 2. System architecture based on a digital twin concept from Altexsoft [9]

4 Implementation and Results

4.1 Hardware Components

4.1.1 System concept and installation

To record the production time, two systems were tested in this case study, as shown in Figure 3.:

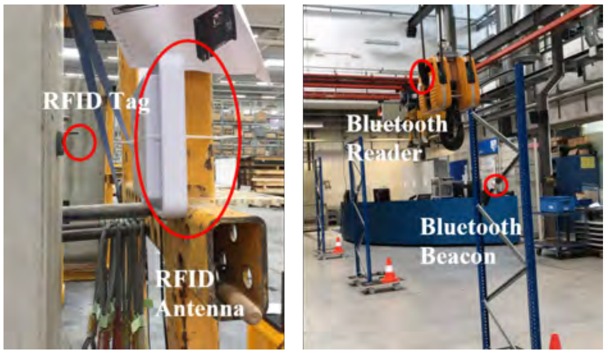

Figure 3. Installation of the two hardware systems

- RFID system: the RFID tags (Omni-ID Exo 750) were tagged on the product, and the RFID antenna (Impinj) stood nearby. Through the antenna, the time of a product entering and leaving the production station was recorded.
- Bluetooth system: the Bluetooth beacons were attached to the scaffold of each station. A Bluetooth reader was attached to the crane. Each time the crane entered or left the area of one working station, the time was recorded. The system of MotionMiners was used in this paper.

Due to the COVID constraints, the Bluetooth experiments were carried out as a feasibility study in the testing facility at the Technical University of Munich.

4.1.2 Test Results

Because of its high equipment cost, in this case study, only the double-wall station was tracked with the RFID system to test the production time as an example. The

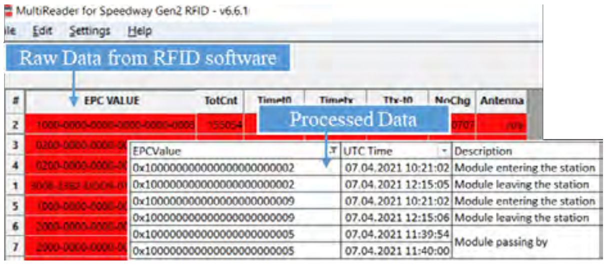

Figure 4. Data samples from RFID system

tag number and timestamp of the double-walls production were recorded, as shown in Figure 4. During the two weeks of testing in the production plant, ten modules were recorded. After processing the data, e.g. filtering the false recorded data, four production time data points are considered plausible by comparing the statement from workers.

For Bluetooth systems, the reader on the crane was able to recognise the RSSI and timestamped Bluetooth signal from the beacons attached to the scaffold. Moreover, the data was automatically transmitted and pre-filtered for outliers. The feasibility of the system has therefore been proven and field tests will be planned at the production plant to obtain real data.

4.2 Software Components

4.2.1 Software Design

The goal from the software aspect is to refactor the framework of the self-developed software and bring it up to date while extending the system for the production floor.

To develop the software components, a detailed requirements analysis is conducted with the users mentioned above. As a result, the requirements are divided into functional and nonfunctional requirements as follows:

- Functional requirements: items table view, warehouse map view, process map view.
- Nonfunctional requirements: data redundancy, portability, usability.

The requirements analysis is visualised by a top-level UML use case model in Figure 5. The red use cases are developed in this case study, whereas the blue use cases already exist in the old software.

To meet the **functional requirements**, the software framework Symfony is used. It consists of a PHP web application framework and a collection of PHP components and libraries. The architectural pattern is the model-view-controller, which splits a software application into three principal logical parts: the model, the view and the controller part. Each of those parts is designed to deal with implementational aspects of the system.

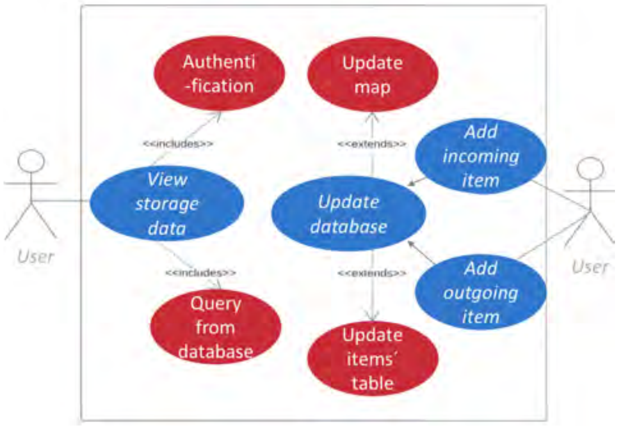

Figure 5. Use cases for the maxmodul application

Furthermore, Twig is used as a template engine and Doctrine is used for object-relational mapping and enabling complex queries to use the object-oriented paradigm of a selected programming language. Among its main features, the ability to query databases using DQL (an object-oriented SQL dialect) is crucial.

To avoid dependency issues and fulfil the **nonfunctional requirements** of portability, the Docker container is used in this project. Docker container creates a ready configured and isolated environment so that any user can run the application easily. In this project, three images are constructed in the container:

- MYSQL: with a mounted volume for data persistence.
- PHP-FPM: with a mounted volume for the application's code.
- NGINX: with mounted volumes for configurations, logs and share mounted volume with PHP-FPM for the application's assets.

4.2.2 Software Implementation

Based on the proposed software design, the initial software is divided into four major artifacts:

- Core: it contains all the business logic, data models and event publishers and subscribers.
- Web: it contains UI elements, their controllers and resolvers, e.g. the map service view or item view.
- API: it contains exposed RESTFUL controllers, API resolvers and object serializers that are still in development.
- Common: it contains parent classes and reusable components for all the elements e.g. controllers,

repositories and resolvers, which reduces the redundancy of codes.

The issues of logic duplication in controllers from the old software are solved with the new structure. Another important change is the introduction of a resolver layer. It handles CRUD and data fetching/providing operations and reduces the workload of controllers. This was initially carried out by the controller in the former software.

4.2.3 Test Results

Since PHP is an interpreted language, it's unable to see the bugs until the program is executed. For this reason, PHPstan is integrated into the project for statical code analysis. PHPStan focuses on finding errors in the code without actually running it. It catches whole classes of bugs before writing tests for the code and detects mistakes in the source code, e.g. calling an undefined method or passing a wrong number of arguments to a function. Also, PHP CS is integrated to detect and fix the violations of pre-defined coding standards in the existing code.

After the refactoring process, the software is extended respectively to the requirements mentioned in 4.2. Concerning the functional requirements, the three requirements in Figure 5 have been satisfied, as the maxmodul application now offers all the required tables and map views. Concerning the nonfunctional requirements, the performance and usability criteria have been satisfied since the application displays all the required information.

5 Discussion and Outlook

In this case study, a concept of digitalization in a prefabrication plant is proposed. From the hardware aspect, RFID and Bluetooth systems are tested. The advantage of the RFID system is that it can be easily integrated but the shortage is the high equipment cost in comparison to the Bluetooth system. In addition, the Bluetooth system enables automatic data transmission and pre-processing. For this reason, the Bluetooth system is preferred and future tests will be based on this system.

From the software aspect, the refactored software is fully functional and has met the user requirements. It is handed over to the company for further test. However, other functions, like APIs for data exchange, should be integrated into future work. On the hardware side, the Bluetooth system should be tested for its performance in the company in the future.

References

[1] Bing Qi, Mohamad Razkenari, Aaron Costin, Charles Kibert, and Meiqing Fu. A systematic review of emerging technologies in industrialized construction. *Journal of Building Engineering*, 39:102265, 2021. ISSN 23527102. doi:10.1016/j.jobe.2021.102265.

[2] Nassim Sebaibi and Mohamed Boutouil. Reducing energy consumption of prefabricated building elements and lowering the environmental impact of concrete. *Engineering Structures*, 213:110594, 2020. ISSN 01410296. doi:10.1016/j.engstruct.2020.110594.

[3] Weisheng Lu, Wendy M.W. Lee, Fan Xue, and Jinying Xu. Revisiting the effects of prefabrication on construction waste minimization: A quantitative study using bigger data. *Resources, Conservation and Recycling*, 2021.

[4] Hans-Hermann Wiendahl: Andreas Kluth and Rolf Kipp. Marktspiegel business software mes – fertigungssteuerung 2019/2020, 2020. URL `https://www.ipa.fraunhofer.de/de/Publikationen/studien/studie-mes-marktspiegel-20192020.html`.

[5] R. Caridade, T. Pereira, L. Pinto Ferreira, and F.J.G. Silva. Analysis and optimisation of a logistic warehouse in the automotive industry. *Procedia Manufacturing*, 13:1096–1103, 2017. ISSN 23519789. doi:10.1016/j.promfg.2017.09.170.

[6] Yanwu Xiao and Jyoti Bhola. Design and optimization of prefabricated building system based on bim technology. *International Journal of System Assurance Engineering and Management*, 2021. ISSN 0975-6809. doi:10.1007/s13198-021-01288-4.

[7] RIB iTwo MES. itwo smart production: Intelligente softwarelösungen für die vorfertigung und modulares bauen, 2022. URL `https://www.rib-saa.com/de/`.

[8] Anne Fischer, Jorge Rodriguez Llorens, Zhen Cai, Michael Wilke, Stephan Kessler, and Johannes Fottner. Implementation of a digital twin framework in the modular housing industry. *28th IEEE ICE/ITMC & 31st IAMOT Conference IEEE*, 2022.

[9] Altexsoft. Digital twins: Components, use cases, and implementation tips., 2021.