Radio-frequency identification based process management for production line balancing

C. Ritter[a], H. Abaeian[b], V. Sirbu[a], and M. Al-Hussein[a]

[a]Department of Civil and Environmental Engineering, University of Alberta, Canada
[b]Department of Building, Civil and Environmental Engineering, Concordia University, Canada
E-mail: critter1@ualberta.ca, abaeian@ualberta.ca

Abstract –

The widespread application of offsite facilities has encouraged the construction industry to make use of manufacturing approaches to develop efficient production systems. To fully realize the advantages of offsite construction, management must be able to effectively schedule production activities to increase productivity and improve time efficiency. This necessitates a tool capable of dynamically responding to real-time production data throughout the process. Radio-frequency identification (RFID) has proven to be a useful technology to provide real-time location data for products moving through a production line and is often used as part of a reporting tool; however, the information provided by RFID also allows for proactive scheduling, which facilitates production line balancing. Maintaining a balanced production line in a variability-prone process requires the end-user to possess knowledge of the production line and the schedule and be able to effectively communicate the production requirements to employees on the production floor. Contextual information, obtained from RFID and measured against job information and production time data, can be delivered to production floor supervisors in real-time in order to enable timely and informed decision-making on the plant floor. This paper introduces a framework for effective production line balancing using data collected by RFID to dynamically update the production schedule and provide more data to help drive better decisions from production floor supervisors.

Keywords –

Offsite Construction; Virtual Manufacturing; Production Line Balancing; Dynamic Scheduling; RFID; Radio-Frequency Identification; Visual Process Management

1 Introduction

A balanced production line is vital in offsite construction manufacturing, given that it decreases wait time and increases the productivity of the entire line. The aim of production line balancing is to divide the necessary tasks into a minimum number of workstations to optimize the total production cycle time [1]. Production line balancing can be considered a Lean tool and is often implemented during the design or setup of a new production line [2]. The line balancing problem has been studied for several years and can be formulated in various ways. One of the original formulations of the problem is the Simple Assembly Line Balancing Problem (SALBP) [3], where tasks are assigned to workstations and precedence relationships are defined. Tasks are then assigned to stations based on the precedence relationships while the takt time, or line cycle time, is used as a constraint to limit station times, thus minimizing the total number of required stations [4]. One of the primary limitations of SALBP solutions is that the inputs and constraints are considered static, while a production line is usually a dynamic operation. Continuous improvement initiatives, constant management input on the production line, and customizable products are examples of inputs that result in an increasingly dynamic problem. Jaikumar and Bohn [5] recognize that the “knowledge, learning, problem solving, and contingencies” introduced to the process by both the production line workers and the management team play a key role in the balancing of the production line.

Maintaining effective communication between management and production line workers is extremely important to ensure that the final product is built to the desired quality, and in the desired time. Production managers must communicate the requirements for supply chain, labor balancing, and production requirements. In order to make these decisions, the production managers require information from the production line, the desired schedule, and the inventory supply chain. The study by Heilala et al. [6] underscores the value of employing simulation with actual data to provide production managers with the information they require to identify potential problems and react to them appropriately. The use of real data and simulation can reduce the time required for information collection by the production manager and allow for effective decisions to be made in less time. Decision support tools, including Gantt charts and scheduling software, aid production managers in making decisions about the schedule and operation of the production line, and also provide an improved method of communicating the findings to production line workers; however, success with decision support systems requires that information be received from other systems, which is difficult to implement [7]. Gantt [8] himself recognized early on that having management specify tasks for workers to accomplish will increase productivity, and the effect will be even greater if any issues are foreseen and managed by the supervisor.

Radio-frequency identification (RFID) is widely used by industry to track components in the production line. Literature proposes the use of RFID technology in tracking precast concrete pieces [9], material delivery vehicles, and construction workers onsite [10]. The basic premise behind RFID systems is similar to barcode technology, but the RFID system stores the data (identification number, code, other object-related information) in tags making it retrievable by specialized readers. Depending on their power source, tags can be recognized as passive or active [10], where passive tags depend on the reader to operate and have shorter read ranges, and active tags use internal batteries for their power supply, which makes their read ranges significantly higher, they have a limited lifetime of 5-10 years and are more expensive due to their local power source. Overall, the specifications of RFID include their power source, read range, read rate, frequency and data storage capacity, and operational life time and cost [9]. Because of the RFID reader's ability to communicate with several tags at the same time, the contents of elements loaded into a manufacturing facility can be captured [11]. While RFID gates are used at pre-designed locations to identify the arrival dates of material to the station, the primary task includes reporting the identification information to the system for further processing [12]. According to Song et al. [13], implementing RFID technology at laydown yards and portal gates paves the way for time savings in material identification, increasing accuracy and shortening time for establishing information on material availability at the plant for further project planning and resource allocation.

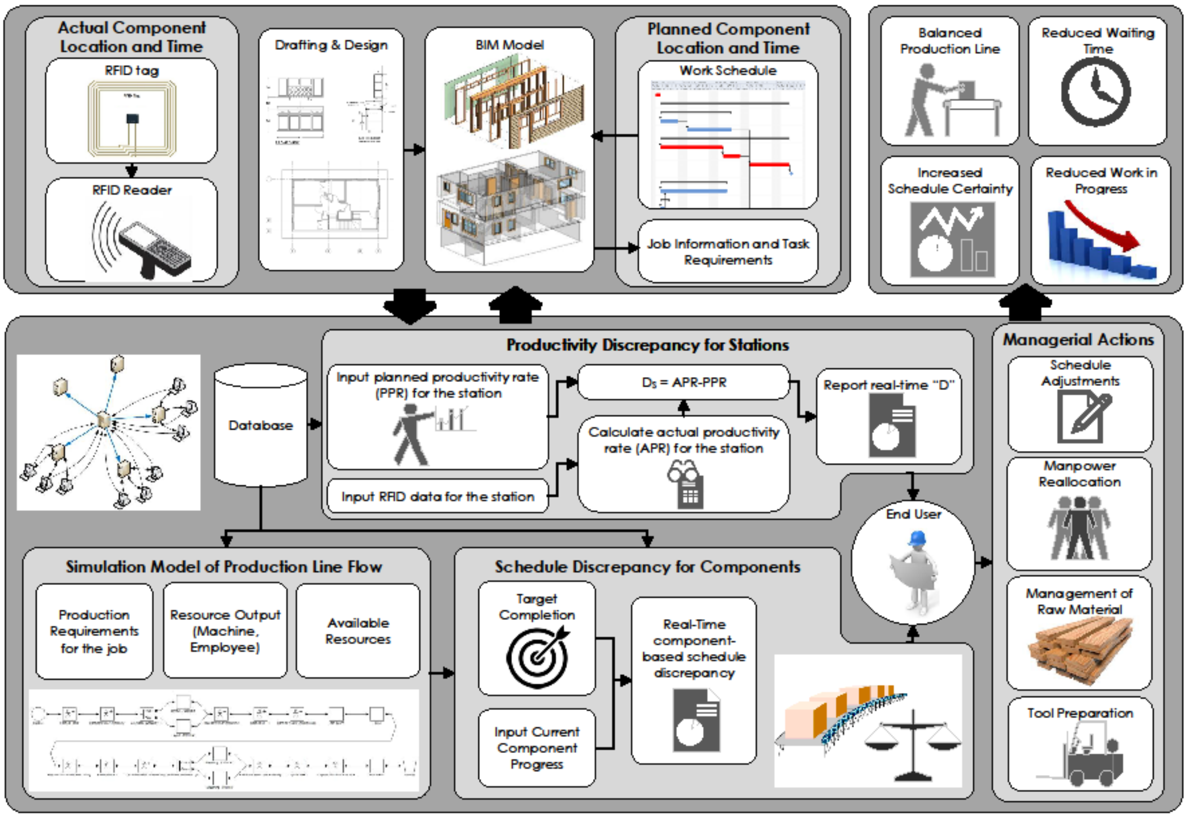

Figure 1. Overview of proposed framework

2 Motivation

A pull system is preferable in a manufacturing setting given that it reduces the work in progress in the facility. Operating a pull system requires knowledge of when each component needs to be completed and how long it will take. This knowledge is usually gained by production managers through years of experience, which leaves the production vulnerable to errors and sudden variations, such as changes in staff. Managers are aided in decision making through reporting, scheduling, and production tracking carried out with the use of RFID data, estimators, and planning departments; however, there is a significant time discrepancy between when information becomes available, when it can be analyzed by the corresponding department, and when it is communicated to the production manager, who only then can make adjustments on the plant floor.

The framework proposed in this paper aims to reduce the time to evaluate and present decision makers with relevant data, allow for the integration of the current plant state into the plan, and to ensure a pull system by planning production progress based on the delivery time for each component.

3 Proposed Framework

The proposed framework utilizes building information modeling (BIM), radio-frequency identification (RFID), and the known work schedule to provide information to production managers or other decision makers in a production facility with reduced delay and necessary manpower. This information will be used to allow the production manager to make more effective, educated decisions while on the plant floor. Figure 1 presents the proposed framework, which is discussed in more detail in the following sections.

3.1 Actual Component Location and Time

The RFID system feeds the last known location of production components to the database. The level of detail for the RFID location is dependent on the number and location of RFID readers in the plant. While the RFID system cannot locate the exact coordinates of any component in the plant, it is able to track the current station each component is in, when it arrives at the station, and how long it has been at the station. This data is used to set the starting point for the simulation model based on the true current state of production in the plant. Using RFID data to determine the current state of the plant reduces the time required for plant managers to collect information about the plant through pure observation.

3.2 Planned Component Location and Time

The information for the planned component location and time is gathered from the work schedule, which will detail the required completion dates for each job; and, the job information and task requirements, together with input from drafting and design and the BIM model, will determine the expected time for the processing of each task in the production line.

3.3 Productivity Discrepancy for Stations

The productivity discrepancy within each station (D_S) refers to the difference between the planned productivity rate (PPR) and the actual productivity rate (APR) for the station. This measure is useful to the end user as it will help to quickly identify the performance of each station compared to that which is expected. These metrics will be available to the end user through a visualization system that enables quick identification of the relative performance of the departments.

3.4 Simulation Model of Production Line Flow

Operating a pull system requires knowledge of the processing time of each station in order to ensure that components will be pulled through the system in a manner that minimizes idle and wait times. The simulation model will use the required completion date for each project along with the BIM model, job information, and task requirements from the database, which will enable the calculation of processing times for each job at each station based on the characteristics specific to each job. The simulation model will then determine how the jobs will run through the production line and interact with one another in order to identify where in the production line each job should currently be in order to meet the required deadline (or as near to it as possible). The simulation model is resource-dependent and built to illustrate the actual case in the plant, including required equipment and its availability, utilization of manpower resources and their limitations, and sequence of production activities required to complete each job.

3.5 Schedule Discrepancy for Components

From the information in the database and the output of the simulation model, the difference between where each component of each job is in the production line and where it should be can be calculated. This discrepancy is important and distinct from the productivity discrepancy of the stations because, even if all stations are meeting or exceeding their target productivity, certain components may be behind the projected schedule that would allow them to be completed by their required completion time.

3.6 Managerial Actions

The information provided to the end user (production manager) will allow for better knowledge regarding the current state of and requirements for production in the plant. The production manager will then be able to make schedule adjustments, such as pulling a component that is ahead of schedule off of the line to allow a component that is behind schedule to accelerate, reallocating manpower to different stations to balance station productivity and requirements based on job types, managing raw material to ensure that there is no wait time or idle time, and preparing tools for certain jobs that are upcoming in the schedule.

4 Proposed Implementation

4.1 Visualization System

To ensure that the end user has consistent access to the production statistics, it is preferred to have a visualization system that can be brought into the production area. This can include the use of tablets or smartphones by the production manager, for which a sketch of the proposed interface is presented in Figure 2. Here, a red bar in the station productivity area (left of view) indicates that a station's productivity is lower than expected, while a green bar indicates the station's productivity is meeting or exceeding that which is planned.

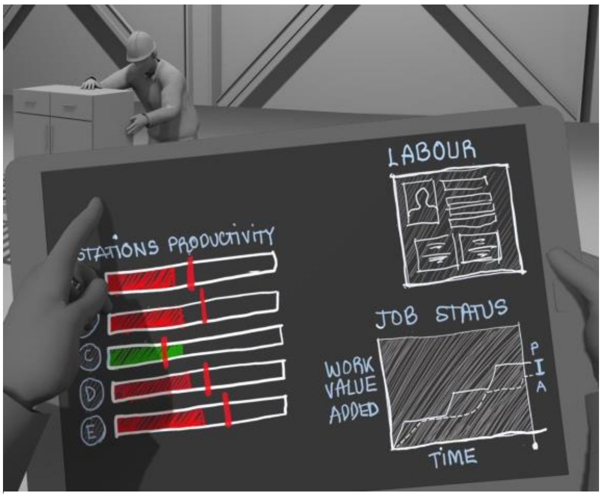

Figure 2. Tablet data display

4.2 Cabinet Manufacturer Case Study

To illustrate some scenarios where the proposed framework would improve on current plant operations, the case of a cabinet manufacturer is described. Change orders, defects and rework, and schedule adjustments all occur in a manufacturing facility and often require production managers to make immediate decisions while on the plant floor. At the time of these decisions, the only information available to the production manager involves statistics and updates gathered at previous meetings or by the manager through current production reporting tools, which often have a significant delay, as well as any information gathered throughout the day by means of observation. This leads to the possibility that the production manager is forced to make decisions based on incomplete information, or that decisions need to be delayed while the required information is gathered. A typical layout for a cabinet manufacturing facility is presented in Figure 3.

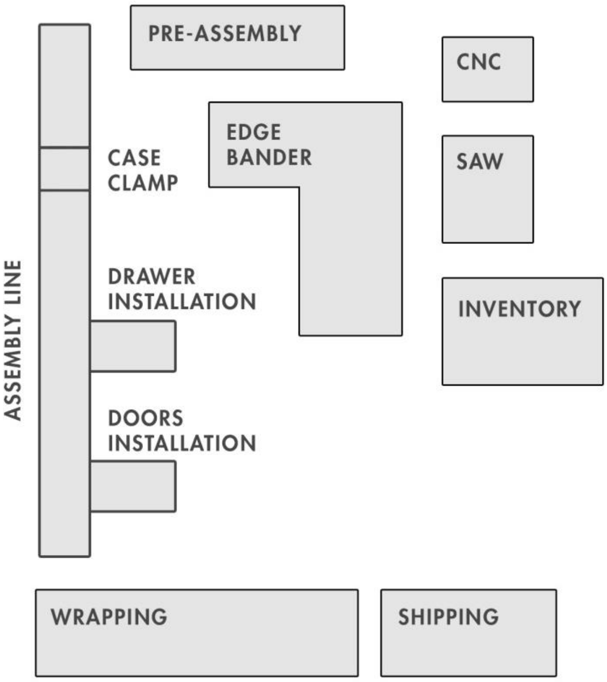

Figure 3. Typical cabinet manufacturer plant layout

One example of a common change that often requires intervention on the plant floor by the production manager is a change in delivery date or schedule change due to material shortage. Most of the cabinets manufactured at the case study facility are designed to be installed in new houses. The date on which the cabinets are needed is dependent on the construction schedule of the house, which can be highly variable. Since the case study plant works closely with partner homebuilders, they have access to construction information and can use this to update the project completion dates to help ensure they are operating a pull system. With the implementation of the proposed system, production managers would be able to track components on a real-time basis, see the outcome of a schedule change on the production line, and be able to make decisions to allow jobs to be processed based on their corresponding deadlines. For example, if one customer of the case study plant is not prepared for the delivery of their cabinets, finishing these cabinets will not benefit the manufacturing plant, as they will then have to store the completed product until it can be delivered. With a daily production of about 200 cabinet boxes per day, and 6-7 boxes fitting on each skid (which covers an area of 1.2 m^2), 31 skids are filled each day. Since the plant only ships orders three days per week, a floor area of 74.4 m^2 is required to store completed jobs between shipping dates. Storing additional finished product reduces the available storage area and reduces production effort available for urgent jobs. The production manager can make changes based on the priorities apparent to them from the information available through the proposed framework to ensure that the production facility maintains a pull system and that wasted storage space is reduced. Also, by the means of the proposed framework, managers would be able to schedule based on the current shipping date of jobs and the estimated production time. The estimated production time remaining is calculated based on the data obtained from RFID and production estimates based on the job characteristics gathered from the BIM model.

The production manager will also be able to monitor the day-to-day production of each station and use this to make labor adjustments to balance the production line. Creating a balanced production line with a variable product such as cabinets is difficult since, with current systems, it is difficult for the production manager to receive continuous details about the plant operations. With the proposed system, the expected workload of each station could be calculated based on job characteristics from the BIM model, and the actual performance relative to the schedule would be consistently available based on the data obtained from RFID, as seen in Figure 2. The production manager could use this information to identify training requirements, to monitor labor efficiency, and to reallocate workers in the plant to ensure each station is keeping up with the schedule. In the case study plant, the pre-assembly area requires the most manual labor and triggers the next activities on the line; therefore, this area has a significant impact on the output of the production line. With the use of the proposed system, the level of productivity at this station would be represented by a red bar, indicating to the production manager that a decision must be made to help increase the productivity at this station. The production manager could then make an educated decision to reallocate workers from another station presenting a green bar (indicating that station is exceeding the planned productivity) to help balance the line. The manager could also decide to implement training for the workers in the pre-assembly area, or to recommend other improvements based on their experience and observations.

Finally, the proposed framework can help to identify and deal with the adverse impacts of rework. For the production manager, being able to instantly show the location of all job components by using the proposed system with up-to-date RFID data, track the job completion progress, or locate a BIM model based on the station being viewed and the job that is currently at that station greatly reduces the time required for valuable information to be located compared to traditional systems. For example, if the case study plant receives a report from a customer about a missing component in the package delivered to their site, the production manager will have instant access to the RFID data for that job and is able to quickly locate the last location at which that component was scanned to help identify the issue.

5 Opportunities and Challenges of Proposed Framework

The proposed framework is intended to address the need to maintain crew work continuity in a construction manufacturing setting. Various interruptions to production line flow, such as plant shutdown, equipment maintenance, employee turnover, variations in productivity, and rework, make it difficult to effectively balance the production line and consistently meet the plant schedule. The proposed framework provides opportunities for improved accessibility of tracking data, efficient communication, real-time schedule monitoring, and innovative data visualization. Figure 2 and Figure 4 present conceptual illustrations of the system from the point of view of the end user.

Common scheduling techniques tend to be complicated to visualize and they lack the means to display the productivity of activities. For example, consider a plant with a productivity rate of 5 jobs per day, where each job consists of 20 units (i.e., 100 units/day); if each includes 6 sequential activities, this would produce a 600-activity network, which may be relatively complicated to schedule and visualize. With the proposed framework, tracking data is easily accessed by the production manager using the system. As illustrated in Figure 2, the production manager can use the system to see the relative station productivities, as well as the more detailed statistics relevant to a selected station or job.

The proposed system will decrease the time required for a production manager to view data required for making effective management decisions, but will still require them to be able to identify the particular job or location they want to see and navigate through the user interface to find the required data.

In the future, this system could be improved through the use of AR as a tool to help the production manager visualize the information; however, current AR technology requires some improvement to ensure that the safety and maneuverability of the manager using the system can be maintained.

5.1 Future Visualization Improvements

The visualization solution would ideally match the complexity of the data presented to the user while considering elements of user experience (UX) specific to factory environments. For instance, safety is a major concern on construction sites and in manufacturing facilities. Computer equipment such as a tablet must be relatively rugged compared to standard office equipment and may require protection from environmental elements such as dust proof enclosures to protect from saw dust. Depending on the manufacturing facilities, these types of considerations must be accounted for. The simplest solution would be to use existing technologies such as tablets and smartphones. Graphs and charts would present the user with context-sensitive data. At the time of writing this paper, 2D data visualization technologies and techniques are mature and relatively user friendly to implement. In his study, Tufte provides guidelines for visualization of complex data [22], making this solution highly feasible; however, it is not without its challenges. Most importantly, tablet screens can distract the user from their environment and could lead to safety issues.

A preferable solution would be to implement augmented reality elements in the visualization. Such a system would ideally use a head mounted display, such as Google Glass or Microsoft Hololens, to overlay the data over the factory view of the user. This would allow the user to move around the factory environment without having their hands occupied and without having their attention diverted back and forth to a screen—a distraction that could be a safety hazard. Furthermore, overlaying data on a real-life scene could enable more effective and contextual data visualization. For instance, 3D CAD models could be overlaid on existing components. This could be coupled with data which describes the length of time needed to complete the operation in the current station, the length of time required for all remaining production for the specific component, or additional information about the job. Figure 4 illustrates how an AR system of this kind would appear to the user.

Detailed implementation of this kind would be contingent on the development of improved technologies that can track the locations of factory elements in real time and with a high degree of location accuracy. As more elements are tracked more data is collected in real time and is run through the simulation. The implementation of a system such as this is also dependent on the development and integration of an AR system that can update quickly enough to satisfy the needs of the proposed framework and allow the system to move wirelessly throughout the plant.

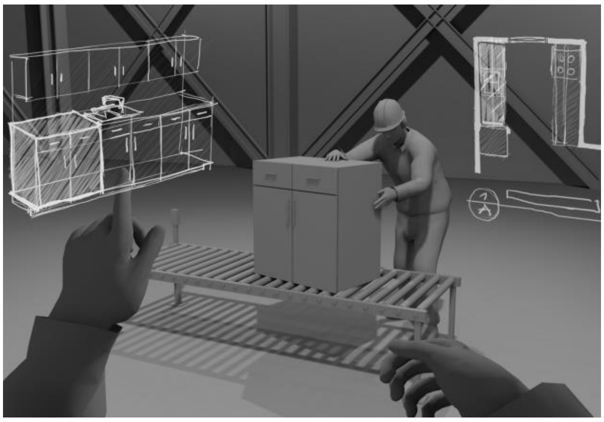

Figure 4. AR overlay of BIM model

6 Conclusion

An effective manufacturing facility requires efficient data exchange between the office and the production line, which enables production managers to make decisions based on the most current information available. The framework proposed in this paper enables the automation of the data exchange and its presentation to the production manager.

The present study integrates the RFID system into the scheduling process and presents the results to the production floor manager. Implementation of the proposed framework provides increased access to tracking data, reduces waste in the communication process, increases the scheduling certainty, and innovatively presents real-time production data to the end user.

Data is currently presented to the user through hand-held devices, such as tablets of smartphones, but could be transferred to AR systems in the future to allow for hands-free viewing, and to enable the user to remain mindful of their surroundings. This transfer should only occur if the system allows for wireless movement throughout the production facility and enables the user to maintain a natural field of view for safety reasons.

References

[1] Sivasankaran, P., and Shahabudeen, P. Literature review of assembly line balancing problems. *The International Journal of Advanced Manufacturing Technology* 73(9-12):1665-1694, 2014.

[2] Karim, A., and Kazi A. A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations. *Business Process Management Journal* 19(1):169-196, 2013.

[3] Salveson, M. The assembly line balancing problem. Journal of Industrial Engineering, 6(3):18–25, 1955.

[4] Battaïa, O. and Alexandre D. A taxonomy of line balancing problems and their solutionapproaches. *International Journal of Production Economics* 142(2):259-277, 2013.

[5] Jaikumar, R., and Bohn, R.E. A dynamic approach to operations management: An alternative to static optimization. *International Journal of Production Economics* 27(3):265-282, 1992.

[6] Heilala, J., Montonen, J., Järvinen, P., Kivikunnas, S., Maantila, M., Sillanpää, J., and Jokinen, T. Developing simulation-based decision support systems for customer-driven manufacturing operation planning. *Winter Simulation Conference (WSC), Proceedings of the 2010 Winter. IEEE*, 2010.

[7] Herrmann, J.W. The perspectives of Taylor, Gantt, and Johnson: How to improve production scheduling. *International Journal of Operations and Quantitative Management* 16(3):243-254, 2010.

[8] Gantt, Henry L., Work, Wages, and Profits, second edition, 1913, Engineering Magazine Co., New York.

[9] Akinci, B., Patton, M., & Ergen, E. (2002). Utilizing radio frequency identification on precast concrete components-supplier's perspective. Proceedings of 19th International Symposium on Automation and Robotics in Construction (ISARC 2002), (pp. 381-386). Washington, DC.

[10] Jaselskis, E., & El-Misalami, T. (2003). Implementing radio frequency identification in the construction process. Journal of Construction Engineering and Management (ASCE), 129 (6), 680-688.

[11] Ergen, E., Akinci, B., & Sacks, R. (2007). Life-Cycle data management of engineered-to-order components using radio frequency identification. Journal of Advanced Engineering Informatics, 21 (4), 356-366.

[12] Goller, M., & Brandner, M. (2011). Experimental evaluation of RFID gate concepts. IEEE International Conference on RFID, (pp. 26-31).

[13] Song, J., Haas, C., Caldas, C., & Ergen, E. (2006). Automating the task of tracking the delivery and receipt of fabricated pipe spools in industrial projects. Journal of Automation in Construction, 15 (2), 166-177.

[14] Azuma R. A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, 6(4):355–385, 1997.

[15] Schmalstieg D. and Höllerer T. *Augmented reality: principles and practice*. Addison-Wesley, Boston, 2016.

[16] Aukstakalnis S. Practical augmented reality: A guide to the technologies, applications, and human factors for AR and VR. Addison-Wesley, Crawfordsville, 2016.

[17] Li X. et al. A. A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction*, 86:150-162, 2018.

[18] Chi H. et al. Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. *Automation in Construction*, 33:116-122, 2013

[19] Irizarry J. et al. InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach. *Automation in Construction*, 33:11-23, 2013.

[20] Candemir O. What's Inside? – Vol 1: Leap Motion. Online: https://medium.com/@candemir/taking-things-apart-vol-1-leap-motion-36adaa137a0a, Accessed: 29/01/2018.

[21] Fazel A. and Izadi A. An interactive augmented reality tool for constructing free-form modular surfaces. *Automation in Construction*, 85:135-145, 2018.

[22] Tufte, Edward. *The Visual Display of Quantitative Information, 2nd Edition*. Graphics Press, Cheshire, 2001.