Efficiencies in the On-Site Material Handling Process by Using Radio Frequency Identification in the Wood Building Construction Industry

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***Abstract*—In the past decades, the housing shortage in Sweden accumulated to a level that led to problems finding accommodation for many people, which created opportunities for the market producing multi-family houses. The market is dominated by concrete solutions whereas solutions using wood as a building material only comprise 9 % of the market. This market is highly competitive with many companies offering relatively similar products or services. One way to develop new business opportunities is to enhance other competence besides production technology that currently acts as a market development barrier. Hence, the material handling process at building sites is seen as a barrier that can contribute improving competitiveness.**

There are currently problems with material handling at many building sites of wood-building solutions in Sweden, materials arrive at the wrong time, waste of storage space, unnecessary tracking of materials or wrong quantities arriving at the sites. The purpose of the study is to investigate if Radio Frequency Identification (RFID) is a technology that can be used to achieve an efficient material handling process and if the wood building industry in Sweden is willing to implement the technology. Thus, investigate if material handling using RFID can improve time effectiveness, minimise waste and monitor moisture levels in the material efficiently, creating improved competitiveness.

The study shows that the use of RFID improves time efficiency and control the material handling, indicating that RFID has potential to improve this process. Further, the study identifies possibilities by using RFID technology to minimise damages and control moisture levels.

***Index Terms*—Material-handling process, building site, JIT, information technology, wood-building, RFID.**

I. Introduction

Companies within the Swedish wood-building industry work towards making the building process more productive and time-efficient without losing efficiency at the building site. Currently, materials are not delivered in the right place or at the right time, and the method of monitoring the material handling process provide opportunities for improvement at many building sites. Further, consideration must be given to the government's climate, and energy target of reducing emissions by 40 % by 2020 compared to 1990 [1]. The construction industry is contributing to this issue due to, e.g. an insufficient ordering process resulting in problems with inventory levels causing unnecessary material handling [2]. The certification BRE Environmental Assessment Method (BREEAM), stimulates developers to improve their capabilities, innovate and make effective use of resources, where an environmental certification can be attained to provide a competitive advantage for the company.

Material handling requirements vary depending on the specific building site, production method, project size or material choice. This can be handled by proper planning by the building companies, combined with a comprehensive project plan. The required quantities for each specific project phase can manually be derived from drawings or through the use of Building Information Modelling, (BIM). However, material handling is an activity that can be complex if poorly managed within the building process resulting in inefficiencies generating higher costs [3]. Problems in the material handling process are some of the most significant and common factors to impact building productivity and are estimated to cause an overall productivity reduction by 40 % [4]. There are several reasons for these shortcomings, such as lost or destroyed material, un-scheduled deliveries to the building site, delivery accuracy. It may also be derived from irregular deliveries based on ad hoc orders due to unplanned material shortages. Developing tools to monitor the material handling process would generate higher efficiency at the building site, which also can enable the possibility to incorporate financial and sustainability targets into the project planning phase at an early stage. Using wireless technology, such as Radio Frequency Identification (RFID), to identify objects combined with, e.g. BIM have previously been tested in the material handling process. This resulted in more controlled material handling, enhanced transparency, increased control, improved time efficiency and waste reduction [5], [6]. Furthermore, poor material handling can cause moisture-related damages in buildings, which is a major concern for the wood-building industry in Sweden and repair costs due to moisture-related damages are estimated to cost multi-billion Swedish kronor annually [7]. Thus, having the possibility for long-term moisture control from the production site to the finalised building, by using wireless RFID moisture sensor may be efficient, providing a possibility for continuously monitoring the material [8].

This study is included in a broader research collaboration between Växjö Municipality and Linnaeus University in Sweden. The research has a primary focus on general activities in the building process for new developments based on wood. These activities include logistics, strategic planning and identification of developers, specific building issues such as moisture, sound and vibration. The studies will provide possibilities for companies within the wood building industry

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to improve its competitiveness. The research is in line with the Swedish government's development towards increased use of sustainable building material for a greener community.

A. Research Goal

The goal is to investigate if improvements are possible within the material handling process for building projects using digitalised tools, such as RFID. Furthermore, to investigate if the building industry can develop the material handling process by implementing RFID at construction sites using wood building solutions, generating a positive effect on material damage, waste, time efficiency, higher quality and long-term moisture control.

II. Review of Conceptual Framework

Detailed plans are required within a building project to facilitate delivery, such as project plan and production plan [9]. Hence, the project manager must know what resources are required linked to the project, i.e. selected building method and the associated costs [3], [10]. Normally, the building materials are delivered and assembled directly. However, this is almost impossible in practice resulting in storage space to handle inbound materials, which require internal transport, machinery and workshops at the building site [9], [10].

A. Material Handling in the Building Process

It is important to have a well-planned strategy for the material handling process considering the complexity at building sites [11]. Identification of products and materials at building sites is traditionally done manually, and deliveries to the building site are checked by reviewing the waybills. Just in time (JIT) enables an efficient delivery plan with high quality that will generate improved logistics and materials handling at building sites, which will reduce on-site storage and provide faster corrections when delivery errors occur [12], [13]. Hence, logistics at building sites must be elevated in importance to take advantage of the customised logistic process, as defined in the JIT process. The purpose of delivery planning is to ensure that deliveries arrive on time and is generated by reviewing the procurement plans, combined with the operational activity plans [10]. The delivery plan can include standardisation of modules and products, digitalised material handling solutions to minimise waste and enable improved transparency at the building sites [14], [15]. It is usually necessary to monitor the material from procurement until the material is delivered at the building site, which can be provided by integrating the digital systems for the material handling process and the building process [3]. However, material management requires to be organised in a way that quality development is still being monitored and developed [3], [11]. Studies conducted by Navon and Berkovich [16], show that the material handling process at building sites needs to be developed and improved and the study reveals limitations in material handling, e.g. wrong time, specification are incorrect and unnecessary tracking of materials. Improving material handling can generate increased productivity gains of 8-10 % as well as a cost reduction due to waste reduction [16].

B. Radio Frequency Identification in the Material Handling Process

There is currently no established standards for information exchange between the actors in the building process making it important to analyse each set-up in advance, ensuring functionality and prevent incompatibility [17]. The Swedish building industry's development found [18] identifies areas within the building production process where RFID has great potential. The project specifically recommends developing logistics and material deliveries with RFID and highlights that synergies are likely to be gained by applying RFID in multiple areas in the building process at the same time. This is supported by the capability of RFID, tracing and identifying objects wirelessly, using an antenna and a microchip containing information, such as date and time, is placed on an object [6], [19]. RFID tags are divided into two main groups, passive and active [6], sending information to a receiver unit that reads the tags and can transfer information to, e.g. a BIM model on a computer via GPRS, cable, 3G, Bluetooth or wireless networks [20], [21]. Building projects are often dynamic and require a large number of products and the ambition is to have the right amount and right type of products, in the right place, at the right time, throughout the project lifecycle [22], which have been tested in the automotive industry for delivery control, inventory balance, transport planning and warehouse activities [23]. Furthermore, there is a demand to locate and track products in real time accurately. Therefore, possibilities to track the location of products with RFID tags equipped with Global Positioning System (GPS), facilitates this demand [24].

Having the ability to merge the material flow with the design process further support the development of RFID data capturing and incorporating it into a BIM model [25]. The purpose of integrating RFID data for the material handling process with project design and BIM is to create a digital link between the flow of materials and the projections based on virtual demand. Where previously interpretation of the information was used is now replace with object-oriented information from original data, facilitating an integrated material handling process, which is possible to transfer the information into a BIM program for further processing, Fig. 1 [25].

The benefits of using RFID technology to coordinate material deliveries via BIM contribute to integrate the supply chain with building planning. In addition to managing and tracking supplies at the building site, RFID and BIM can also be used for controlling and documentation purposes. Thereby, in real time, provide information regarding when a product has been produced, its quality status and if it is ready for delivery [24]. Thus, inform the building site to prepare for reception and installation, as well as provide information regarding products which have already been installed. Further benefits using RFID in wood-building solutions are related to more than 80% of building damages can be considered to be moisture-related [7], which can be controlled by moisture measurements using RFID during the building production phase as well as for lifecycle management. The benefit of

RFID is that the same tag could be used for material handling purposes as well as for moisture control in different phases of the production process [26], [27]. Furthermore, Onysko *et al.* [28] mention that moisture levels influence the total energy consumption as well as the material shrinkage. This can be controlled through radio waves by moisture sensor using RFID technology that wirelessly measures moisture in the material [29]. When the tags are placed in a material that contains moisture, the difference in impedance between the tags can be related to moisture level or humidity [30].

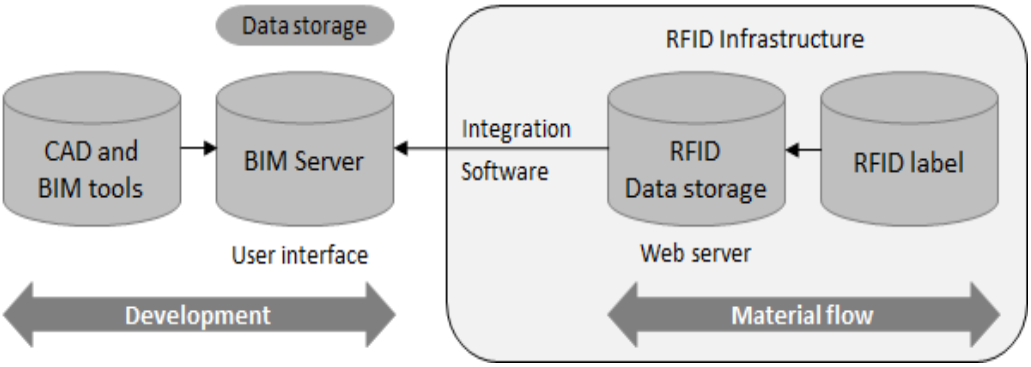

Fig. 1. Information flow based on RFID.

In a case study for a water supply project conducted by Ren, Sha and Hassan [31], RFID was used to support the project team collecting and storing materials, facilitating the flow of information regarding material requirement, i.e. material planning, ordering and monitoring. Also, in a previous case study on window deliveries displayed potential for improved control of the material flow using RFID [19]. The case study illustrated that the material flow becomes more efficient and errors are reduced using an automatic documentation process. RFID is a supportive tool for improving the efficiency of the material handling process throughout the supply chain, which is based on careful planning of the business to maximise the possible synergies of using this system [19].

III. Research Process

Data were collected on 14 medium-sized building projects in Sweden between May and November 2017, and the selected projects for this study are new building projects of townhouses, co-operative apartments, and rental apartments using predominantly a wood-based building solution. Several persons were interviewed at each site to provide a broader perspective, and the respondents in this study held functions such as production managers, production engineers and project engineers. The selection criteria for the respondents are senior people that are involved in the projects, which provides high reliability. Furthermore, mapping the material flows and providing an understanding of the material handling process on each project were performed in conjunction with the interviews [32].

The primary objective was to collect information regarding how improvement within the material handling process could be achieved using digitalised tools. The research goal influenced the selected research design in different ways, and the research process is perceived as primarily exploratory with descriptive components [33], [34]. This is an appropriate research approach for the complexity faced in cases such as the material handling process at building sites, according to the study by Yoshikawa *et al.* [35], which provides a structured view for a cross-sectional study identifying the most important factors influencing this process. The data were initially analysed qualitatively to establish general trends after that analysed quantitatively using a mixed methodology to provide greater depth and range than a single method could deliver [36], [37]. Thus, the choice of combining qualitative and quantitative deliverables in this study was motivated by the material handling process for wood-buildings not being reviewed in this context earlier [35]. It allowed to capture the full scope of the processes within a complex context and to identify transferable understandings by the respondents [38]. Also, using an interview in fulfilling the research objective is applicable when explanation and description is required as in this study [33].

The interviews were in person and took between 35 and 80 minutes, with an average of 60 minutes. The interview template had questions designed around, RFID application and general understanding, the material-handling process and moisture related concerns associated to the on-site building process, which were verified as important areas during the pre-interview sessions providing a transparent view of the studied field. All interviews were documented, thereafter analysed by reviewing the responses, compiling the material and summarising them using systematic text condensation [39], [40]. This generated an understanding of the material handling process regarding how the respondents perceived the activities [40]. The quantitative data analysis was based on 17 questions based on a 5-graded Likert scale, where 1 indicates no importance and 5 indicates high importance [41] and 6 sub-questions. The quantitative information, i.e. grading the response from 1 to 5, was based on the respondent's perception of the process. The Likert scale items are created by calculating a composite score from five Likert-scale criteria's that were analysed at the interval measurement scale. The sub-questions that can't be answered by the 5-graded scale use percentages, or a yes or no option, to indicate how the industry perceive these questions.

By using systematic analysis of the result and by ongoing discussions between involved researchers and industry stakeholders provided improved validity and reliability of the study [42]. However, there is a constant development of technology that could result in studies carried out with similar objectives at a later date resulting in different conclusions.

IV. Project Result and Analysis

A. Material Handling Process

The method for material handling at the studied building sites are similar, although there are differences based on working conditions for the various projects and therefore is adapted to the needs of each independent building site. However, 93.75 % of the building projects use some degree of prefabricated building method, which requires similar challenges regarding material handling. Prefabricated parts are often larger building components that need to be delivered just in time to facilitate an efficient material handling process, which is discussed by Jonsson and Mattsson [11] and Akintoye [13] as important to improve time and space utilisation. Despite the importance of proper planning, the main part of the work is done on a basic planning board at the site office. This is, according to the respondents used to update the project timeline and to provide general information at the building sites, which are important activities for project success as discussed by Persson [9]. Further, specific plans for purchasing requirements are made displaying who will perform the purchase, when the request is to be sent, when ordering has to be made, as well as the delivery date. The respondents grade the reception and inbound delivery process as 4.22, which indicates this as an important activity connected to the project purchasing, Table I. Furthermore, the purchase plan is synchronised with the project plan to avoid excess materials to be stored on site. Despite a high focus to coordinate the purchase plan with the production plan according to Table I, focus on verifying order fulfilment is low in importance, 2.88. This is contradictory to the study by Révai [10] discussing the importance of resources control for project fulfilment. Confirming the delivery accuracy back to the supplier is also indicated as of low importance, scoring only 2.18. However, the general pursuit of cost control and time efficiency was important by the respondents and supported by Persson [9].

All projects have similar methods for receiving inbound deliveries where the requested delivery time and delivery location is noted at the time of ordering the products. According to the respondents, approximately 60 - 70% of the deliveries arrive at the building site on time. However, the result shows poor communication is considered to be the primary cause of insufficient material handling. The relatively unstructured approach regarding the material handling process is discussed in the study by Navon and Berkovich [16], identifying these problems as being derived from a low priority of logistics at building sites. Sometimes materials are delivered directly to subcontractors on the building site, resulting in un-authorised personnel accept deliveries, which may cause the delivery to be lost due to poor communication by the sub-contractor. Storage locations for materials existed on all sites and in many cases in excess capacity, which is reflected by the responses in Table I, scoring proper routines for on-site storage as 4.17 in importance. The respondents also highlighted the importance of proper planning for material that requires special care, such as dedicated or covered space. Further, it is important to take into account transport routes, which has been proven to be important success factors for the studied projects and also mentioned in the study by Jonsson and Mattson [11] as important activities for an efficient material handling process.

TABLE I: Material-Handling Process

1. What is your perception of the routines regarding on-site storage?	4.17
2. How is the material stored at the building site?	
Dedicated space	26.32%
Under roof	31.58%
Tarpaulin	21.05%
Outside	21.05%
3. How important is the reception/delivery process of materials in the building site?	4.22
4. To what extent are the deliveries verified compared to orders at the time of delivery?	2.88
5. How often is confirmation sent that the right material delivered?	2.18
6. How important is the work to get on-time deliveries?	4.60
7. What delivery methods are used?	
JIT integrated production plans	53.33%
High storage levels	20.00%
Digital planning tools	0.00%
Orders against production plan	26.67%
8. Is it common for materials to be delivered early and take place at the building site?	3.40
9. How significant are faults and problems in the material flow?	3.63
10. Where do they normally occur?	
Delivery to a building site	66.67%
On building site	33.33%
Returns	0.00%
Additional activities to facilitate handling	0.00%

TABLE II: Moisture-Related Concerns at the Building Site

1. Are you considering building under tents to minimise moisture-related damage associated with material handling?	2.00
2. How important are defined moisture quotas for purchased material and finished buildings?	4.67
3. Is the control of moisture quotas an important activity at the building site?	4.83
4. When do you control the moisture quotas?	
at delivery	22.22%
upon installation	44.44%
before sealing-up the building	11.11%
during the life-span of the building	22.22%
5. How important is it to cover material stored outside?	3.25

Materials that arrive before the scheduled delivery date is considered a problem since the material cannot be kept safe without jeopardising damages. This is displayed in Table I, scoring the importance of on-time deliveries 4.60, which is reinforced by Akintoye [13] and Révai [10] mentioning the benefits of JIT for efficient production and resource control. The material that is being delivered early occupy space used by workers, leading to inefficiencies by extra movements of the material, which requires additional time and risk of damaged material. Also, it is important that materials are protected from rainfall, which can be an issue if material arrives early with no available storage space. The respondents score the importance of covering material outside 3.25, Table

II, displaying an above average focus on this for moisture control. This is contradictory towards the perception of the high importance placed in controlling moisture levels at the building sites, which according to Table II is scored as 4.83, which also is mentioned in the study by Dietsch *et al.* [27].

The main reason material arrives in advance is orders being produced in advance as a preventive measure since it is not possible to rely on deliveries being accurate at the projected time. This is not mentioned as a major concern for the projects included in this study, providing a score of 3.40 according to Table I. The best solution is JIT; the material is placed where it is scheduled to be used, in the right amount and at the right time, which is the material handling method used by 53.33 % of the respondents, Table I. This is also supported by Olhager [12], emphasising the operational benefits of JIT. However, all respondents describe problems with the material flow with back orders that will contribute to time delays affecting the production plan. Backorders can be delivered to the wrong storage areas since the original order was split up causing additional time locating the material. The majority of the projects included in the study strive towards JIT for improved material handling, yet the problems persist. Andersson and Hultberg's [29] study show that excess materials storage at the building site creates additional safety, as materials are always available when required. Further, the study presented by Persson [9] underline the importance of a well-planned and stringent process to optimise the material handling activity improving project fulfilment. Despite the material handling process working in practice, there is great potential for improvements developing a completely digitalised material flow process, from planning to the reception at the building site, including invoice management. This study shows that all the occurring problems were difficult to eliminate, but the respondents express an ambition to improve the problem using new technology, such as RFID.

Moisture control within the material handling process is presented in Table II, scoring the importance of adhering to pre-determined moisture quotas as 4.67 for the included wood-building projects. It is also important that material is protected from rainfall, which is an issue if material arrives prior to schedule. This is mentioned by the respondents and score the importance of covering material outside as 3.25, Table II. This is slightly contradictory towards the respondent's perception of the importance controlling moisture levels at the building sites, which in Table II is scored as 4.83, and according to Sandin [7] relates to 80 % of all building damages.

B. Future Scenarios Using RFID

All projects use a dedicated digital program for quantifying the required material, which easily can be distributed digitally to all involved parties. Only a few projects use BIM's automatic quantifying feature. Based on the studied projects, BIM could be used to a greater extent together with RFID, creating integrated plans facilitating an efficient building process. This can be done by integrating the building site plane with virtual storage locations that automatically can be updated on the general project plan, which would provide increased project transparency and material control. However, none of the respondents mentioned BIM and RFID as suitable tools for creating integrated digital plans, which was a method mentioned by Sørensen [25] to further enhance the improvements in the material handling process. Further, accessibility and availability are important for efficient material handling at building sites placing large objects near the usage point. These activities are discussed in the study by Olhager [12] as being important for the quality and efficiency of the material handling process by improving resource utilisation.

TABLE III: DEVELOPMENT OF DIGITALISATION

1. What value do you think a system has that allows easy review of deliveries?	4.01
2. How do you look at introducing digitised methods to work more efficiently with material handling?	3.10
3. Is there a value to easily read what is on a pallet without breaking the packaging?	3.62
4. How much do you know about RFID?	1.69
5. How do you look at the possibility of placing a chip containing information that increases information availability?	3.44
6. Appropriate product groups for RFID implementation	
Wood, wood products and plaster	23.0%
Bulk products	20.7%
Windows and doors	14.9%
Machines and tools	14.4%
Plumbing and ventilation	6.3%
White goods	4.0%
All material categories	4.0%
Theft-prone products	4.0%
Additional building frames/bodies	3.4%
Insulation	2.9%
Volume products	2.3%
7. Do you think that RFID, or similar technology, can improve time-efficient used in material handling?	3.70
8. Do you plan to implement RFID in your process in the future?	
Yes	28.6%
No	71.4%

The respondents included in this study were positive towards using RFID in the material handling process, and they believe that RFID technology may be useful for controlling deliveries. This is also confirmed in the study by Dehlin *et al.* [19] display improvement in the material handling process is contributed to implementing RFID. However, according to Table III, most respondents were not aware of RFID or its capabilities regarding the material handling process, scoring it 1.69. Most of the respondents believed that it would be beneficial if information could be sent automatically when the truck approaches the building site, leaving them time to organise the unloading activity. This is also mentioned in Table III, where the respondents score this activity 4.01, making the efficiency of the receiving process at the building sites important. Further, this functionality would provide an opportunity to verify if deliveries have arrived. The study conducted by Dehlin *et al.* [19] also emphasised the benefits of RFID, providing increased control in the material delivery process and improved accuracy due to an automated documentation process. However, they believe RFID is primarily suitable for the supply of certain material, such as wood, wood products and plaster (23.0 %), bulk products (20.7 %) and windows and doors (14.9 %). They are also positive to link the transportation to BIM, thereby identify where in the process material are located for improved planning at the building site, which is a functionality

improving efficiency mentioned by Backman [20]. This will provide opportunities to stop shipments planned to arrive earlier than scheduled and redirect the shipment to be stored externally, which is a control feature discussed by Sardroud [24].

Goods receipt is a problem at building sites based on the size and complexity of the performed activities. Using RFID for improved control of the material flow is according to discussions by Dehlin *et al.* [19] a solution since all packages or pallets arriving at the workplace could contain passive tags containing a unique identification number that the RFID system can use to identify the shipment. Thus, both the transport company and the recipient can see that the delivery is complete directly at unloading, which could be a solution automating the waybill process for larger shipments. This is a solution that the respondents have mixed opinion about, scoring the ability to improve the material handling process by attaching tags to shipments 3.44, indicating average importance. The demand to track products and to integrate them into the building plan in real time is high according to the respondents, which would be possible through the integration of BIM and RFID enabled with GPS according to the studies made by Sørensen [25] and Sardroud [24]. This study has shown that larger building sites specifically have a great demand for accurately being able to locate materials in the workplace. However, the respondents consider the barrier implementing new material handling technology as a constraint for this development, despite this study showing that control of inbound material deliveries can be improved using RFID technology. This is in contrast with the benefits of real-time tracking of material discussed by Sardroud [24]. Hence, an alternative would be for the transporter to apply passive tags to larger packages, which are scanned using a handheld receiver unit.

Besides these initial concerns, using RFID is considered as positive and a necessary development that is confirmed by the cases study performed by Ren, Sha and Hassan [31], presenting efficiencies in material planning, handling and order. Therefore, seamless integration of all activities at the building site, including a time-efficient material handling process is scored 3.70 by the respondents, Table III. This makes RFID an important tool for the development of the material handling process at building sites in Sweden. One obstacle developing RFID is the conservative nature of the building industries and advantages using RFID are difficult to verify from an economic viewpoint considering financial benefits often involve hidden costs, such as damage, delayed or missing delivery. This might imply that the industry is currently not willing to make a transition towards an automated material handling process using RFID at building sites. This is reflected by only 28.6 % of the respondents consider implementing this technology in the future, Table III, which is contradictory to the benefits using RFID displayed in the case studies made by Ren, Sha and Hassan [31] and Dehlin *et al*. [19].

V. Discussions and Conclusion

The material handling process would benefit from increased digitalisation considering it is still quite unstructured regarding data integration and operational activities. However, it is necessary to develop methods to utilise enhanced digitalisation, i.e. increased collaboration in the building process to develop openness regarding project planning and access to integrated project data. Further, the companies in the building process can to take advantage of this opportunity and use the increased digitisation of information for simulations for specific and complicated stages during the building process. Labelling products facilitate identification and tracking of products at external sites, which provides improvements for planning, managing and following up deliveries to the building sites.

It is indicated that only part of the material flow will change at building sites if implementing RFID in the material handling process, which means that other parts of the process should continue and focus on quality improvement activities. If RFID is used to generate profit and efficiency, the primary focus should be on creating sustainable core processes by the development of, e.g. purchase planning, JIT, production planning and transportation. Therefore, building sites ought to focus on working with a more automated JIT system to fully incorporate the benefits of RFID. However, there is a risk that RFID would contribute to a negative development for the material handling process if a well-developed JIT process is not established before implementing RFID. Therefore, this would only be suitable for certain types of products at an early stage. Products that are fragile and prone to theft are good examples of where RFID can be beneficial initially. Hence, products being labelled with an RFID tag enables faster and more transparent receipt process, saving time by identifying shortages and provide ample time for new deliveries and minimising operational disturbances. Further, the disclaimer process for any delivery shortages will be completely transparent facilitating discussion regarding responsibility and financial liability between the involved parties.

Moisture damage has been a recurring problem in the building industry. Materials get lost on building sites, moved several times causing damages, or the material is placed in a location where weather damage may occur increasing the possibilities for long-term damages. Therefore, improvements in reducing these problems are needed, which could be solved using RFID technology for long-term monitoring of moisture levels in the material. Hence, moisture controls using RFID can be a better option for a sustainable material handling process regarding moisture related damages. Further, the corrective actions are minimised if moisture is detected by RFID tags at an earlier stage. Therefore, unnecessary time spent handling damages is prevented if RFID moisture sensors detected moisture levels at an early stage. Adopting RFID for monitoring moisture levels in the material does not change the material handling process and implementing this technology would not be a significant challenge for most companies. Therefore, this technology can be a suitable tool for several building sites that strive towards improved time-efficiency by minimising problems derived from moisture damages.

The study indicates that the use of RFID can improve time-efficiency in the material handling process and the technology is well developed and is already widely used in

several other industries and markets. The building industry is positive to RFID's technological development potential regarding material handling and indicates interest to develop this potential further. There is a general requirement for increased control throughout the material handling process, where RFID has displayed potential to improve delivery control and the goods receipt process. Implementing RFID technology would provide some change for the producers or transport companies providing the deliveries, which could influence successful implementation of RFID technology.

This study also identified a demand for active tracking of materials at building sites, which is possible when connecting active RFID tags and GPS. Active RFID tags have been suggested to be more beneficial on large projects, which can display financial savings justifying the higher costs of active RFID tags. Another option for improved control of the material handling process is to implement larger numbers of passive RFID tags, which involves more responsibility for the building workers, resulting in increased time spent in comparison to active RFID tags.

REFERENCES

[1] Ministry of Environment and Energy. (2015). Klimat och energimål till år 2020, (Climate and energy goals until year 2020). [Online]. Available: http://www.regeringen.se/sb/d/8756/a/123033

[2] C. G. Hanberg. (2014). Miljöcertifiering ökar byggnadens värde. *Environmental Certification Increases the Building's Value*. [Online] Available: http://www.byggnyheter.se/2014/01/milj-certifiering-kar-byggnadens-v-rde

[3] U. Nordstrand, *Byggprocessen, (The Building Process)*, Liber AB, 4th ed. Sweden: Stockholm, 2008.

[4] S. Razavi and C. Haas, "Using reference RFID tags for calibrating the estimated locations of construction materials," *Automation in Construction*, vol. 20, no. 26, pp. 677-685, 2011.

[5] N. Köhler. (2009). BIM gör att arenabygge ligger långt före tidsplanen. *BIM allows for the Arena Construction to be Far ahead of Schedule*. [Online] Available: http://byggindustrin.se/artikel/nyhet/bim-g%C3%B6r-att-arenabygge-ligger-l%C3%A5ngt-f%C3%B6re-tidsplanen-16316

[6] C. Roberts, "Radio frequency identification (RFID)," *Computers and Security*, vol. 25, pp. 18-26, 2006.

[7] K. Sandin, *Praktisk Byggnadsfysik, (Practical Building Physics)*, Sweden: Studentlitteratur AB, Lund, 2010.

[8] M. Islamovic, "Cross-Laminated Timber – En fallstudie av Hyttkammaren samt en jämförelse med prefabricerat betongelement ur platsomkostnadsperspektiv, (Cross-Laminated Timber – A case study of Cabin House and a comparison with prefabricated concrete elements from a cost perspective)," M.S. thesis, Halmstad University, Halmstad, Sweden, 2013.

[9] M. Persson, *Planering Och Beredning av Bygg- Och Anläggningsprojekt, (Planning and Preparation of Construction Projects)*, Sweden: Studentlitteratur AB, Lund, 2012.

[10] E. Révai, *Byggstyrning, (Building Control)*, Liber AB, 4th ed. Sweden: Stockholm, 2012.

[11] P. Jonsson and S. A Mattsson, *Logistik - Läran Om Effektiva Materialflöden, (Logistics – the Science of Efficient Material Flows)*, Sweden: Studentlitteratur AB, Lund, 2011.

[12] J. Olhager, *Produktionsekonomi: Principer Och Metoder för Utformning, Styrning Och Utveckling av Industriell Produktion, (Production Management: Principles and Practices for the Design, Management and Development of Industrial Production)*, Studentlitteratur AB, 2nd ed. Lund, Sweden, 2013.

[13] A. Akintoye, "Just-in-Time application and implementation for building material management," *Construction Management & Economics*, vol. 13, no. 2, 1995.

[14] P. Jonsson, *Logistics and Supply Chain Management*, United Kingdom: Mcgraw-Hill Education, 2008.

[15] R. Andersson and A. Hultberg, "Materialhantering i byggbranschen: En jämförelse mellan Just In time-leveranser och lagerföring på byggarbetsplats, (Material management in the construction industry: A comparison between Just In Time deliveries and warehousing)," M.S. thesis (M.Sc), KTH Royal Institute of Technology, Sweden, 2012.

[16] R. Navon and O. Berkovich, "Development and on-site evaluation of an automated materials management and control model," *Journal of Construction Engineering & Management*, vol. 131, no. 12, pp. 1328-1336, 2005.

[17] M. Olander, "RFID i byggproduktion – Praktiska fallstudier,(RFID in building production – practical case studies)," *SBUF Rapport 12237*, 2010.

[18] SBUF, (The Swedish building industry's development found), "RFID och BIM i byggproduktion,(RFID and BIM in building production)," *Technical Report, NCC Teknik, SBUF Projekt 12459*, 2011.

[19] S. Dehlin, J. Fredhsdotter, and C. Claeson-Jonsson, (2010). RFID-tagg och skrivare. Användning av RFID i bygglogistik med inriktning på finsterleveranser. RFID Tag and Printers. *The Use of RFID in Construction Logistics, Focusing on Window Deliveries.* [Online] Available https://www.yumpu.com/sv/document/fullscreen/20272889/anvandning-av-rfid-i-bygglogistik-med-inriktning-pa-sbuf

[20] J. Backman, "En sammanlänkning av material- och informationsflöde med RFID och BIM, (A combination of material and information flow with RFID and BIM)," M.S. thesis, Lulea University of Technology, Sweden, 2012.

[21] K. B. Sørensen, P. Christiansson, and K. Svidt, "Ontologies to support RFID-based link between virtual models and construction components," *Computer-Aided Civil and Infrastructure Engineering*, vol. 25, pp. 285-302, 2010.

[22] H. Cai, A. Andoh, X. Su, and S. Li, "A boundary condition based algorithm for locating construction site objects using RFID and GPS," *Advanced Engineering Informatics*, vol. 28, pp. 455-468, 2014.

[23] G. Levander, S. Lindgren, and R Larberg, "RFID-teknik inom fordonsindustrin," *Slutrapport: Projekt RFIDNU, (RFID Technology in the Automotive Industry), Final Report: Project RFIDNU)*, Odette Sweden AB, 2008.

[24] J. M. Sardroud, "Influence of RFID technology on automated management of construction materials and components," *Scientia Iranica*, vol. 19, no. 3, pp. 381-392, 2012.

[25] K. B. Sørensen, "Virtual models linked with physical components in construction," M.S. thesis, Aalborg University, Denmark, 2009.

[26] A. Motamedi and A. Hammad, "RFID-assisted lifecycle management of building components using BIM data," in *Proc. 26th International Symosium on Automation and Robotics in Construction*. Austin, Texas, USA, 2009.

[27] P. Dietsch, A. Gamper, M. Merk, and S. Winter, "Monitoring building climate and timber moisture gradient in lage-span timber structures," *Journal of Civil Structure Health Monitoring*, vol. 5, pp. 153-165, 2015.

[28] D. M. Onysko, C. Schumacher, and P. Garrahan, "Field measurements of moisture in building materials and assemblies: Pitfalls and error assessment," *Best Conference–Building Enclosure Science & Technology*, 2008.

[29] A. Andersson and N. Edmond, "Marknadsundersökning för en fuktsensor med RFID-teknik, (Market survey for moisture sensor using RFID technology)," M.S. thesis, Mid Sweden University, 2011.

[30] J. Sidén, X. Zeng, T. Unander, A. Koptyug, and H. E. Nilsson, "Remote moisture sensing utilizing ordinary RFID tags," in *Proc. IEEE SENSORS Conf. in San Diego, USA*, 2007, pp. 308-311,

[31] Z. Ren, L. Sha, and T. M. Hassan, "RFID facilitated construction material management — A case study of water supply project," *Advanced Engineering Informatics*, vol. 25, pp. 198-207, 2007.

[32] L. T. Eriksson and F. Wiedersheim-Paul, *Att Utreda, Forska Och Rapportera, (To Investigate, Research and Report)*, Liber AB, Malmö, Sweden, 2011.

[33] L. M. Ellram, "The use of case study method in logistics research," *Journal of Business Logistics*, vol. 17, no. 2, pp. 93-138, 1996.

[34] R. K. Yin, *Case Study Research: Design and Methods*, Los Angeles: Sage Publications, 2014.

[35] H. Yoshikawa, T. S. Weisner, A. Kalil, and N. Way, "Mixing qualitative and quantitative research in developmental science: Uses and methodological choices," *Qualitative Psychology*, vol. 1, 2013.

[36] N. B. Wallerstein, I. H. Yen, and S. L. Syme, "Integrating social epidemiology and community engaged interventions to improve health equity," *American Journal of Public Health*, vol. 101, pp. 822-830, 2011.

[37] D. M. Mertens, "Transformative mixed methods: Addressing inequities," *American Behavioral Scientist*, vol. 56, pp. 802-813, 2012.

[38] J. Lucero, N. Wallerstein, B. Duran, M. Alegria, E. Greene-Moton, B. Israel, S. Kastelic, M. Magarati, J. Oetzel, C. Pearson, A. Schulz, M. Villegas, and E. R. White Hat, "Development of a mixed methods investigation of process and outcomes of community-based participatory research," *Journal of Mixed Methods Research*, pp. 1-20, 2016.
[39] S. Kvale and S. Brinkmann, *InterViews: Learning the Craft of Qualitative Research Interviewing*, London, Great Britain: SAGE Publication Ltd, 2009.
[40] K. Malterud, "Systematic text condensation: A strategy for qualitative analysis," *Scandinavian Journal of Public Health*, vol. 40, no. 8, pp. 795-805, 2012.
[41] R. Likert, "A technique for the measurement of attitudes," *Archives of Psychology*, vol. 140, pp. 1-55, 1932.
[42] J. L. Whitten, L. D. Bentley, and K. C. Dittman, *Fundamentals of System Analysis and Design Methods*, 6th ed. Los Angeles: Case Study Research, Design and Methods, Sage Publications, 2014.

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