Requirements for RFID Tagging Process of Concrete Elements in Building Project

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Abstract: **Concrete elements can be divided into many different types (e.g. façade elements, pillars and hollow slabs) which all have their own characteristics. We have completed two pilots to collect experience of embedding RFID (Radio Frequency Identification) tags into concrete elements, its effects to the different phases of a building project and processes related to them. The requirements of identification may vary for each type of these elements. The tagging process and the needs may also be divergent. Our experience clearly shows that identification of elements using RFID in larger scale requires remarkable engagement from the parties involved in the supply chain. The assurement of the readability of RFID tags in a completed building requires elaboration and clearly defined processes already during the modeling of a building. In this research we have focused on the information related to the elements and identification at defined action points to provide useful status data. This status and information is produced through all the manufacturing chain from production post-control.**

1. INTRODUCTION

RFID technology has been piloted in various construction industry cases lately. There are numerous different application areas where RFID can put into good use. Employees may be tagged to control who has accessed or left the building which can provide valuable information in case of an accident such as a fire or it can just be used to control the employees' movement and time spent into different tasks. Tools may also be tagged to identify and track them [1] and even to store the operation manuals [2]. According to the National Insurance Crime Bureau, the construction industry in the United States lost nearly $1 billion in 2001 because of the theft of equipment and tools [3] and the expenses have even been increasing. An average of 33% of the theft incidents are thought to involve employees or former employees [4]..Being aware of who is occupying a tool or who is responsible for it might drive employees to take better care of the tools and also prevent thefts.

Nowadays concrete elements are mainly identified using paper or plastic tags with human readable serial numbers and bar codes. These tags are attached at the element factory and removed at the latest after the erection. Since these tags are attached outside the element, they occasionally detach causing additional examination about the type and identity of an element at the construction yard. Because the tags will eventually be removed, additional information for control and verification or serial numbers for identification cannot be left to the completed building. Tags embedded into an element do not hold this limitation. Tags casted inside the element are hidden and will be left into the element. Passive tags will stay functional long after the construction project is finished giving a chance to take advantage of the technology also in post-control or maintenance. This creates possibilities for using the identification at the latter part of the element life-cycle as well.

Embedded RFID tags in concrete elements may be used in various forms. They can carry information, such as dimensions, weight and raw materials or they may include some functions of sensor technology to collect information. Another approach is to use the tags only for identification. In this case, product-related information is stored into information systems. Depending on the case, either of these approaches can be good for information availability and usability.

Tags can also be used to track and trace items. In supply chains, one of the most important benefits is the information about passing the defined action points. Passing these points can be converted into changes of element status. Element factory may provide information when element is casted, stored or ready for transportation. Availability of this information may be essential for project management and supervision on construction site. Real-time information about installed elements may be important for the progress of a project as well. When this information is saved into information systems, scheduling can automatically be ensured and exceptions can be detected.

Our approach in this research project has been to identify the construction elements. The focus of this paper is on the tagging process of concrete elements. Embedded passive tags only contain a serial number that is used to link the element to the related data on information system. During the pilot cases we have found out that tagging and information management requires collaboration between the companies in supply chain to enable the usability of RFID through the element lifecycle from manufacturing to the time years after the building has been finished.

2. RFID IN CONCRETE ELEMENT IDENTIFICATION

The read range of passive RFID tags is rather limited. This sets some requirements and challenges for the tagging process, since the tags cannot be attached into any location of an element. In [5] different types of tags embedded in

concrete elements have been tested. Non-customized passive HF (High Frequency) tags were proven to be the most usable in this application area since UHF tags have problems with detuning when the radiowaves have to penetrate through materials. In our case with embedded tags this has a significance. One of our objectives was also to research the mobile usability in real-life environments. Since there are commercial HF-readers that can be used with mobile phones via Bluetooth, the HF technology was chosen to be used.

2.1 Tagging Requirements

Various parties have to be involved in the process of tagging to make the identification process functional through the element life-cycle. To guarantee the functionality, RFID tagging has to be taken into consideration already during design and modeling since other objects or walls may block the access to the tag after interior installation. Nowadays BIM-applications (Building Information Modeling) are often used for design. These cad-type modeling applications may include the information about the structures in very precise level and may also include support for scheduling the different phases of objects.

Figure 1 presents two installed elements. Another of the elements has 3 embedded tags and only one of those tags is well-readable. It is located close to the inner surface of the element and is not blocked by any fixed obstacle. Another of the blocked tags is installed in a position where another element will block the readability whereas the other is installed into wrong side – too deep in the element when read from inside of the building. However, both of these misplaced tags are readable before installation.

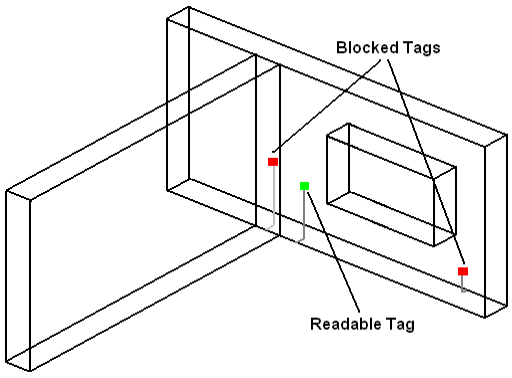

Figure 1: Different tag positions in an element.

The next concern for RFID tagging process is connecting the unique serial number of RFID tag to the ID of construction element. The element may actually have numerous different IDs. BIM application may use its own internal identification while element factory uses their own ID in the production planning. In some cases when there are numerous identical elements, unique ID values are not even significant or visible for many phases of the chain, but some general element type is used instead. This might later cause problems for information system and building model management since identical element typically get mixed up with each other.

The role of the used information system for these two pilots was to manage the relations between different IDs and the information about the tag locations in each element. The system operates as a centralized integration server connecting and managing the information provided by various external applications. In these pilots the original 3D-model was imported from a BIM application using the implemented Web Service interface. The main purpose of the system is to automate the quality assurance process, but these functions were not needed in these pilots.

The relation between tag ID and element IDs can be generated in different ways. First of all, this relation can be bind in office environment using a desktop application. In this case the element IDs and other related information has to be printed in RFID tags to make the construction workers aware of which tags need to be attached to which elements. Another option for creating the relation is to do it at the casting site, for each element one at a time. The workers may carry mobile phones or PDA devices that can be used to create the relation. They can use RFID reader embedded in the device to read the serial number and fill the unique element ID by hands or by reading the bar-code using the camera embedded in the device. Both of these solutions have their advantages and disadvantages and can be used depending on the preferences of the company. Based on the interviews [6] with the employees on element factories having experience about RFID tagging, both of these techniques have their supporters.

After the RFID tag is linked into an element in the virtual model, it will be attached into an element during the casting. As suggested, tag needs to be attached to the pre-defined location in the element. Instructions need to be passed to the worker along with the construction drawing and it may be individual for each element. However, some general rules and best practices about the location should be agreed to ease the later reading process.

2.2 Related Work

There are existing solutions where RFID tags have been used to identify elements. Typically the tags are attached outside the elements to be mainly used for identification on-site. Enterprixe [7] has created a model based web service to pass the information about element installations where RFID is used for identifying concrete elements. The mobile solution is based on Nokia NFC mobile phones. Because of the limitation of embedded reader, the tags are attached outside of the element. This solution provides the benefits of wireless identification, but has the same weaknesses with paper/plastic tags: loosen tags and the need of removal before completion of building.

Wang [8] introduces an RFID-based quality management application for concrete specimen inspection and management. They have considered also the two methods of tag attachment; either embedded directly to the concrete specimen or attaching the tag using a rope. However, deeper analysis of tagging or agging process are not considered.

The functionality of semi-passive or active tags can also be exploited. Tags can be embedded to concrete elements or casting to monitor the temperature thus controlling the concrete maturity [9]. This can lead to decreased construction times while providing the information about when the built constructions are durable enough to carry on the fabrication. This may also improve the safety aspects. Concrete maturity measurements have also been piloted and analyzed by Hansen and Surlaker [10].

3. PILOTING THE TAGGING OF ELEMENTS AND ITS EFFECTS TO THE BUILDING PROCESS

We have completed 2 pilots to get experience of the tagging process and the usability of RFID on-site after installation. We were using Philips BC ISO15693 contactless cards carrying 64-bit unique identifier. These slim credit-card sized (54 mm x 85,6 mm) tags do not have any fasteners for joining. Therefore the tags had to be embedded either on the upper surface of an element or in some cases pushed to the side of an element. The tags and elements were linked to each other using a web-based interface to the information system and the configured tags were visually marked with element IDs. Tags were delivered to the casting site and employees were responsible themselves for finding the appropriate tag for each of the casted elements.

3.1 Pilot I: Partly Identical Pillars

The first of the two pilots was completed with pillars. The building containing more than 100 pillars was divided into three segments and all of the 36 pillars of third segment were tagged. Among these pillars there were 8 different models involved. The manufacturing and tagging were completed on item level, but at the construction yard only the element type was considered and item level identifiability was not used. Maintaining the traceability of each element precisely afterwards will be one of the challenges and the divergence has to be linked in the construction plan.

The information about the elements to the information system was imported from Tekla Structures BIM application. Identifiers, dimensions, information about scheduling and completed actions can also be imported and exported between these systems through the implemented interface. Therefore timestamps and other information, such as exact installation location, can be exported to Tekla Structures as well. In different building projects this may be valuable information during and even after the project.

Figure 2 represents the installation of a tag into a pillar. The installation is completed right after the erection while concrete is still soft. In this pilot the installation location was agreed to be in a stationary location to ease the searching process and to make the reading after installation possible.

Figure 2: Embedding a tag to a pillar.

The search of installed elements proved our concern of disorganization of elements. Not only the elements casted for the third segment had been mixed with each other but some got also mixed with the elements in other segments. The missing and found tags are presented in Figure 3. Green circles represent the found tags, arrows where the tagged elements in other segments should have been installed and red rectangles represent the elements where the tags were completely missing.

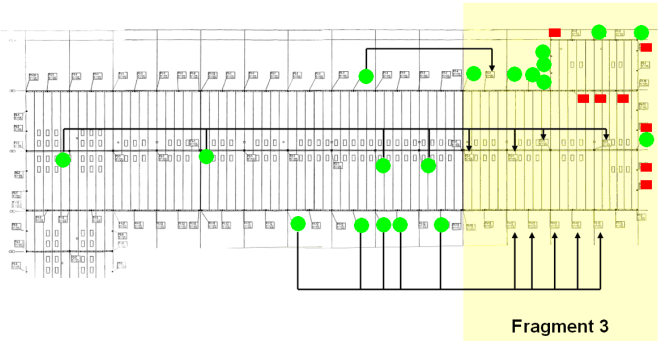

Figure 3: Tagged pillars after installation.

After a careful search for the tagged elements, we were able to find 19 out of 36 tags. Only 9 of these tags were found from the predetermined section. Since the used construction plan only consisted of element types, not IDs, there is no advantage of analyzing the potential mix up between the identical elements. Although the casting of the elements was completed in predefined order, the storing of the elements at the factory and at the construction yard caused the mix up between the elements in different fragments. 8 of the tags were not installed to the pillars at all. This was because of a human error at the element factory. The remaining 9 tags that could not be specified demonstrate other problems. Since there were already some additional wall elements installed at the time of the tests clearly

blocking the access to the vicinity of the optimal position of an element, our deduction is that these missing tags were embedded in these elements. There is also a possibility, that some of these missing tags simply did not work, was installed to a completely incorrect position or was installed so that the reading was impossible, such as too deep in the element or too close to supporting steel structures.

3.1 Pilot II: Tagging Façade Elements

The second pilot consisted of 12 tagged façade elements for a terraced house. All of these elements were unique and therefore the mix up with each other was not considered as a problem in this case. The major purpose for the tagging was to make possible the linking of measured main dimensions for the element and passing those values to the construction site. This however gave us a change to check the readability of tags from erected building.

The information related to elements was imported to our system from the production planning system of the element factory. This type of manufacturing execution application does not give a chance of defining the placement of a tag in an element based on the placing of an element and its relations to others. Therefore we compromised over the placing. The tags were placed on the inner (upper) surface of the elements, 40 cm from the side and 130 cm from the bottom of the element in 3 cm depth. This was done to prevent the blocking of overlapping elements while the reading the tags from completed building. This turned out to be a successful decision since all the 12 tags were found with ease. However, this single case does not prove that this approach is reliable. Instead, we again notified that planning or at least verifying the location of each tag is important to guarantee as good functionality as possible.

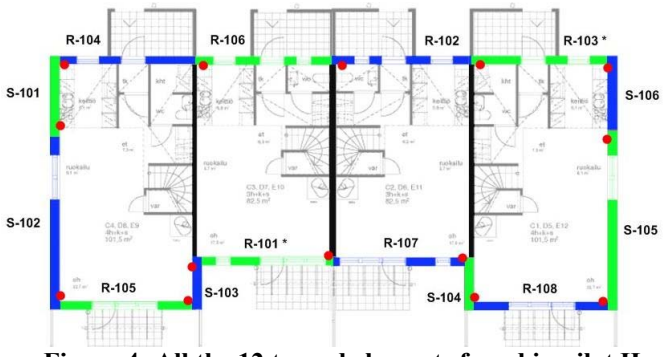

Figure 4: All the 12 tagged elements found in pilot II.

4. SUGGESTED APPROACH FOR RFID IDENTIFICATION PROCESS

The completed pilots have shown that there has to be a clearly defined location for the RFID tags attached into an element. The first step on each project is to define the fundamental location where the tags are attached to for each element type. This location should provide a good readability in each of the phases in the chain. A commonly followed location makes it a lot easier to find the tag from the element in each phase. The readability in finished building should also be taken into consideration. There are other elements and structures that may block the readability after installation. To guarantee the readability in this phase the RFID tag locations should be specified and verified also in construction modeling application. However if a single tag is attached into a different position compared to others, this information should somehow be accessible for the person who is later on trying to read the tag. If he does not know the exact location, he either has to go through whole the element spending a lot of time or more probably he will just skip the element.

Based on the pilots, we have divided the actions related to the tagging of concrete elements in 8 main steps:

1. Create general company rules for tagging. This includes the definitions about the depth and preferred tag attachment locations for used tag types, fixation and attachment methods and directions. The rules also have to follow the needs of the partners.
2. Search for the optimal position for tags in the selected project elements. This depends on the goal and purpose of identification in different phases. Compare the general rules to the requirements and select the most suitable location.
3. Add the tag positions to the BIM model. At this point the tags blocked by static obstacles in building should be located from the model. Locations for these tags have to be defined individually. Other requirements, such as identification in the other parts of the supply chain, have to be considered.
4. Inform the constructors about the attachment positions for the elements and potential exceptions.
5. Create the links between RFID tags and elements in BIM software. This connection can be made at the office when constructor has to find the appropriate tag for each element or the constructor can create the connection using a personal mobile device just before casting.
6. Install the tags into the elements.
7. Verify the functionality of installed tags. If exceptions occur, inform the modeler.
8. During the installation of elements store the element location into the BIM model.

Based on the experiences, the parameters related to these steps can be adjusted later on to develop and improve the functionality and usability of identification.

If diverging and individual locations for tags are used, the attachment position information should be available for the one who is reading the tags. This may however turn out to be a challenging matter to be solved, especially in the cases where the person is not aware of the mixed up elements. This just indicates how important it is to have a minimum number of predetermined attachment locations.

One solution to ease up the discoverability during the tag reading process could be using some visual mark to present the location in element, e.g. paint. This approach is usable only during the construction process, since finished and visible elements will be coated or painted. If the surface is already finished in the factory, this type of marking cannot be done.

One of the challenges might also be reading of multiple tags simultaneously. With current technology this is not a problem because of the short read range, but if the range was longer, this problem might occur. Therefore one might have to consider, if some information in addition to the unique ID should be stored to tag to make the identification easier. This could also be taken into account while defining the locations to tags, not attaching the tags too close to each other.

A successful RFID tagging process requires a high-level commitment from the organizations that are involved in the project. Not only the management but also the workers have to be taken into account. Since tagging is a multi-phase process and requires co-operation of several parties, education and motivation is also an important issue. Special caution is required when completing projects with tagging alongside the traditional projects without tagging. As noticed in the first pilot, workers may easily forget to attach the tags if tagging is not one of the common parts of manufacturing.

5. CONCLUSION

As presented in this paper, tagging of concrete elements is not only attaching the tags physically into elements. To guarantee the best available readability, tagging process has to begin during the modeling to find the optimal and convergent location for tags in each element. The attached tags need to be linked into the elements in the model during the tagging and the information about the installation spot of each element at the construction site has to be taken into the construction model. Following these steps guarantees the functionality and usability not only during the construction process but also after the installation of elements and completion of the building.

Our pilots illustrated that there are risks in utilization of RFID. Employees may forget to attach the tags into the elements. This problem grows when the elements in some projects are tagged and in some not. Other variables such as hurry may also cause carelessness. In conjunction with the technology limitations and readability, RFID should not be used as an exclusive identification method, but always needs to have supporting identification method aside.

One of the open questions is if there is some additional information that could also be written into the tag besides the identification number. As a basic rule this information should at least be static and not updateable. The accessibility of tags is and will always be a restricting factor and to prove that the information shared is up to date, no changing information should be written into the tag. In addition, this information should also be stored in information systems to guarantee the availability of information when needed. The memory capacity of a tag is also limited which limits the amount of information to be written into a tag.

One of the challenges in larger scale projects would probably be to create a change to the old habits and operation models. Requirements for successful tagging process and the usability for the whole life cycle require also good co-operation between the parties in a construction project. Some of the companies in supply chain may not have any obvious advantages of the technology but still may need to be using it. Especially in these cases the management of the participating companies must be committed and the employees have to be trained to have sufficient know-how about their assignments. Therefore good regulation is in key position for a successful project.

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