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USE OF EMBEDDED RFID TAGS IN CONCRETE ELEMENT SUPPLY CHAINS

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SUMMARY: *Precast concrete components are basic element of modern construction industry. Their lifecycle involves many steps, in which the element's progress is usually tracked on paper. Similarly construction projects do not often have a formal information management process. Increased traceability and information management could address issues related to duplicated information management work, lack of real-time information, information delays and access issues. A study of how an information system can be integrated to the construction process and what kind of services can be implemented with the unique tracking of precast concrete elements is reported here. The tracking and data management is implemented with embedded RFID chips in each of the elements. The viability of building information modelling, traceability, management, gathering of quality management data and logistics location management services are shown to work with a series of pilot projects. The information system increases the amount and the detail of data, providing more tools for data management and reduces the amount of human errors involved in information management.*

KEYWORDS: *mobile technology, radio identification, logistics, supply chain, construction, information technology.*

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1. INTRODUCTION

Precast concrete elements are building blocks of various building projects. They come in different shapes and can form the entire supporting structure of a building. During its life cycle, presented in Fig. 1, a precast element will pass through many stages, e.g. planning, manufacturing, storage, transportation, pending installation queue, and installation. Current state information is important so that the construction site can confirm that parts have been received in correct order and they can proceed on schedule.

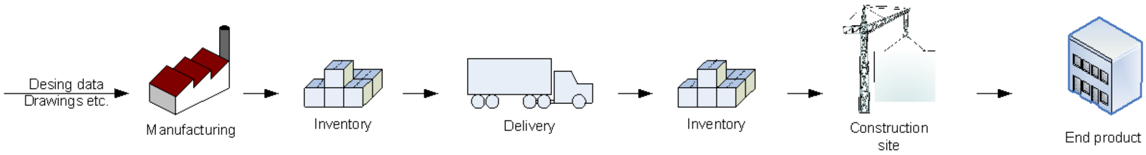

FIG. 1: Supply chain for precast elements.

Traditionally, status updates, defects in construction objects and quality inspection records are marked on paper by a construction worker. Workers collect this information during the workday and deliver it to the project manager at the end of the shift. Knowledge management of construction projects is often formed on an ad-hoc basis and does not serve the project's needs as well as a designed system could (Carrillo et al., 2000). The traditional approach has problems and challenges related to information management, which have been recognized by researchers (Kimoto et al., 2005; Ergen et al., 2007; Lin et al., 2007; Leskinen, 2008), namely:

- Duplicated work;
- Lack of real-time information;
- Information delays;
- Information access issues.

A current drawback to information management in construction logistics is that the traceability of the elements through the logistics chain is often poor, because the elements are not tracked in detail and might be grouped with other elements of a similar model. The details available from the construction site storage might be just on the level of recently arrived deliveries and beyond that, the manager has to do phone-based queries. Additionally, many reports from the construction site have to be gathered manually and input to the information systems. In a worst-case scenario, the produced reports, such as daily defect reports, remain in paper form and are not shared efficiently or are lost. A recent study by Torrent and Caldas (2009) noted that construction labor hours can increase by up-to 16-18% if required materials and components are not ready when needed. If potential problems can be detected at an early stage, there are better opportunities to react and reallocate resources.

Traceability is not the only problem present in construction, but rework costs are a major element of total construction project costs, with the cost of rework being as high as 6% to 25% of contract price (Josephson, 1999; Barber et al., 2000). However, in construction projects where a quality management system was implemented, the cost of rework can be only 1% of contract price (Love and Li, 2000). Effective quality management requires accurate and current information about the quality issues for improving the processes and planning the rework (Love, 2002). The lack of information or poor information can lead to needless rework and increased construction costs (Love, 2002). This means that accurate information tracking and quality management can lessen the need for repeated work, because quality issues can be caught in time.

The poor management of knowledge about the precast logistics chain leads often to delays and repeated input work, which might discourage workers from entering exact data all the time. This means that the information available in information systems and shared with partners is not necessarily up to date or as accurate as possible. Logistics and production decision-making would benefit from exact and up-to-date information about the status of precast components, allowing decisions to be made earlier and based on more accurate data about what is happening in the field.

Traditional forms of information dissemination, such as phone, email or SMS, are ineffective and time-consuming. Better tracking of the elements through the logistics chain would enable the automation of information management and the implementation of services that utilize the more accurate tracking data, like automatically collected and targeted quality management data. The collected data can be gathered and processed automatically for computerized presentation in BIM (Building Information Modelling) programs, which have been found effective in construction management (Yusuf Arayici, 2012).

The nature of information storage at construction sites has been perceived as a problem and different kinds of information management systems have been developed for it, each addressing a different issue from logistics tracking (Song et al., 2007) to quality inspection (Dong et al., 2009). RFID (Radio Frequency Identification) is a heavily researched and a quickly maturing technology as well (Ngai et al., 2008). However, these problems are still often examined from separate aspects, with the field lacking a system that combines automatic identification, tracking, mobile quality management and measuring into one cohesive whole.

The aim of the research presented in this paper is to improve construction project logistics processes by improving information handling and increasing traceability. The main research questions are:

- Which kind of changes does a construction logistics chain require in order to support accurate traceability of elements through the entire chain?
- What services can be provided with the help of improved traceability?

The research approach is design science, in which a solution is designed to address a specific problem and the solution's validity is confirmed by its utility (Hevner et al., 2004). In this case the first step is to first examine the current state of construction element logistic chains, the existing implementations of tracking and the suitability of different machine-readable identification systems for the transported elements. After examining the problem a new construction project information management system is designed and implemented based on the lessons learned in earlier research. Finally, the validity of the chosen approach is tested by using the information management system services in a series of pilots.

This paper analyzes the logistics chain of precast concrete elements, from manufacturing in the factory to installation and post-control on site, and details an approach to implementing a computerized real-time quality management for precast elements. An approach is presented where mobile devices are used to provide access to a centralized project information system and RFID (Radio Frequency Identification) is used to guarantee permanent and efficient identification of elements. The aim is to present an approach to construction logistics management systems where information can be shared more efficiently among the participants of a project and overall in the project the information is more available and up-to-date.

The presented application of design science research method (DSRM) consists of six steps (Peffers et al. 2007). The Table 1 shows how they are applied in this study and how each step of the activity corresponds to a step of the research presented in the paper. With the problem defined earlier in the introduction section, the following sections present the steps from two to five: The design, demonstration and evaluation of the design science artifact. In this study the artifact is the tracking process and the information management system for precast concrete elements in construction.

TABLE 1: Design science research method activities

Activity	Description	Activity in this study
1. Problem identification and modification	Define the research problem. Knowledge of the state of the problem is required.	The problem of disorganized information was recognized by examining earlier studies. They show that tracking and information management at construction processes could be improved.
2. Definition of the objectives for a solution	Create objectives for a solution from the basis of problem definition and knowledge.	Because the problem is the difficulty of tracking and information management, the chosen solution is to implement a tracking method that can provide tools for improving several aspects of the process.

3. Design and development	Create the artifact by designing a desired functionality, architecture and the actual artifact itself.	The tracking method for elements and the information management system are designed and described.
4. Demonstration	Demonstrate by, for example, a simulation, a case study, or experimentation how well the use of the artifact solves the problem. In this stage it is required to know how to actually use the artifact to solve the problem.	The designed system is tested in a series of case studies that implement different services on top of the tracking or information management system.
5. Evaluation	Observe and evaluate how well the artifact actually solves the problem.	The utility of the implemented solution is evaluated based on its effect in the case study processes.
6. Communication	Communicate the problem, the designed solution, and the artifact to the researchers and other audience.	Communication is carried out by publishing the presented paper in a scientific journal.

The paper is constructed as follows. Following the introduction and motivation for the study, element identification is addressed in section 2. Accurate element identification is seen as essential for effective management of construction industry processes. Section 3 covers the proposed solution for project management through a centralized management server. The system architecture and its components are explained. Section 4 presents the research plan, the performed case study, examines the construction process supply chain and how the proposed solution can be utilized. The paper concludes by presenting conclusions and discussing future development ideas for the construction industry.

2. CONCRETE ELEMENT IDENTIFICATION

Each precast concrete element has to be identifiable throughout the whole supply chain and, therefore, is labeled during production. Elements may be identified in sets by their type or by their unique serial number. During interviews with construction industry representatives, it became apparent that there is a need to identify each element uniquely using some type of serial number to ensure tracking. This is important because identical looking pieces may have different attributes, e.g. steel reinforcements that are not necessarily visible after casting. These identifiers have to remain the same through the whole supply chain or be linked to each other so that all the cooperating companies can identify the elements.

Identification methods can be divided into visual- and radio-based methods. Visual identification can be carried out with human readable characters or different types of machine-readable bar codes. Radio-based identification makes possible advanced types of identification scenarios compared to visual identification.

2.1 Visual element identification

Most identification systems in the construction industry are currently based on visual identification. Identification marks and codes are typically printed on external labels that are attached to the elements in the factory, or in some cases, painted on the element.

One of the limitations with using external labels is that they are attached to the element in a factory and removed during or after installation, and therefore, the traceability of a single element ends at this point, unless precise information about each element and its location is brought to the as-built building information model and is accessible afterwards. Since these labels are attached to the outside of the element, they can occasionally become detached or be destroyed during transportation. This always causes additional examination work in the construction yard to ascertain the type and identity of an element. Visual element identification can be divided into human readable and machine-readable methods.

2.1.1 Human readable identification

Visual element identification is typically done using coated paper or plastic labels which are human interpretable and attached to the elements. The elements are mostly handled by humans and there is little automation in the identification process. Labels typically contain specific information such as dimensions, weight and possibly acknowledgements of passed inspections. An example of a plastic identification label can be seen in Fig. 2.

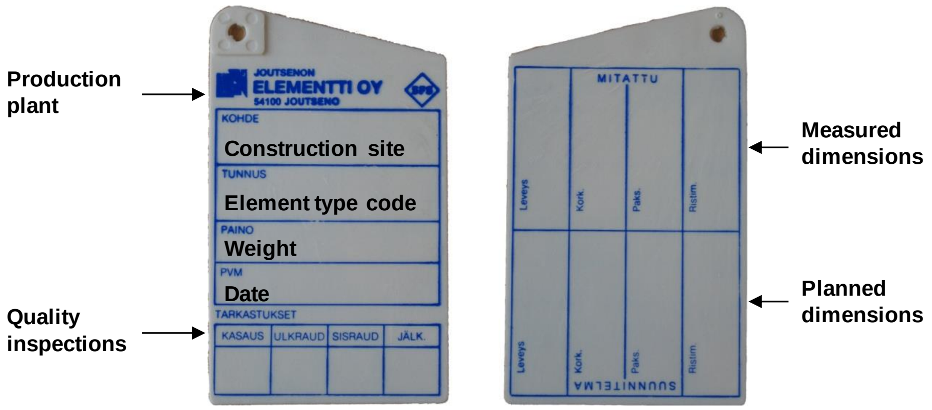

FIG. 2: Example of manually filled in label used for identification of precast concrete elements (front and back).

2.1.2 Barcode identification

In addition to human readable information, precast element labels can include visual machine-readable information such as barcodes. Machine readable identification has gained popularity as the identification process can be speeded up and human based keystroke errors can be avoided. If the reader devices are able to communicate directly with company databases, they can update status information of the inspected object. Typically, a barcode consists of a serial number or another identifier that is used to identify the target. An example of a precast element label with a traditional one-dimensional barcode is presented in Fig. 3. The label also includes content such as weight, project, and precast element type in human readable format to ensure proper identification even if the barcode should become damaged and unreadable.

FIG. 3: Coated paper label with 1D barcode of an element identifier.

Linear 1D-barcodes have been used since the early 1970’s (Malvido et al., 2006) and the technology has been proven usable and accessible; laser readers can give multi-meter reading distances. Although various research papers considering 1D barcode recognition with camera phones have been published (Ohbuchi et al., 2004; Wang et al., 2005; Wang, Zou, et al., 2007; Wachenfeld et al., 2008), proper reading of 1D-barcodes requires high-resolution devices. Decoding of 1D-barcodes with current mobile devices has therefore proven to be challenging. Several enhancements to traditional decoding techniques have been proposed in order to improve recognition rates, for example, based on statistical methods (Wang et al., 2005), or on digital signal processors or other extra equipment (Ohbuchi et al., 2004).

2D-barcodes have gained interest as they have the potential to store more data than 1D-barcodes. For example, Data Matrix symbology, which is widely used in the aerospace, automotive and medical industries for package labeling, can store up to 3316 numerical or 1556 8-bit ASCII characters (Falas and Kashani, 2007). 2D-barcodes also have lower requirements for the reading device resolution. Kato and Tan (Kato and Tan, 2007) have completed a read rate analysis of 2D-barcodes for camera phone applications, with measured maximum reading distances varying between 16.9 and 21.7cm depending on the barcode technology used. Thus it is possible to use camera equipped mobile devices if the reading conditions, such as lighting, are sufficient. While reading of 1D-barcodes is typically sweep-based, reading 2D-barcodes is image-based.

2.2 Radio signal based identification

Visual identification is not the only method for machine-readable identification. Another approach is the use of Radio Frequency Identification (RFID). A typical RFID system consists of a tag, reader, their antennas, and electronics controlling their operations. One of the major benefits of RFID compared to barcodes is that there is not necessarily a need for line-of-sight between the tag and the reader. In addition, the RFID tag can carry more data, which makes it possible to convey more information about the product. Updating the data on a tag is also relatively simple and fast, since there is no need for printing and attaching a new tag as with printed labels. Utilizing RFID in the construction industry has received attention from other research groups as well (Akinci et al., 2002; Jaselskis and El-Misalami, 2003; Umetani et al., 2006; Yin et al., 2009).

RFID tags are typically divided into three categories based on their energy consumption (Roberts, 2006). Passive tags use no internal power source; the power for transmission is gained from the signal that is sent by the RFID reader while it is scanning for tags. Active tags contain an internal power source, which is used to strengthen the transmission. This naturally lengthens the reading distance of a tag but also makes the tags more expensive and results in a limited lifetime. The third category, semi-passive tags, contains an internal power source, which is used to enable internal functionalities such as temperature measurement. There are benefits and drawbacks to each technology, but passive tags are generally most suitable for embedding in products, because the access to the tags can be a problem after the product is finished.

Another classification of RFID tags is based on the radio frequency that the system operates. Different RFID frequencies react differently to the surrounding environment, tag attachment, and intervening material. The effect of different materials varies depending on the wavelength used, but metal is a significant problem for all frequencies (Kallonen and Porras, 2007).

2.3 Summary of identification technologies

Identification of concrete elements in the construction process is important for a safe and efficient building process. Identification methods need to support the work of the builders so that the errors can be avoided. Visual identification with clear information about each element makes it easy to check the information of each element. Usage of visual labels enables identification during the construction process but not normally after installation. However, visual labels are also prone to break in harsh conditions, and updating typically requires re-printing and manual work. Our tests also established the potential of RFID tags in harsh real-life conditions, where they endured much better than printed visual tags and other studies have had similar findings (Wang, Lin, et al., 2007). The Table 2 shows the relative benefits of each of the identification systems, with the specifications simplified for the purpose of comparison.

TABLE 2: Comparison of element identification methods

Identification method	Human-readable	Machine-readable	Read range, up to	Data stored	Durability	Identifier lifecycle
Visual label	Yes	No	~1-3m	2-3 sentences	Low	Manufacturing - Delivery
1D barcode	No	Yes	1-10m	< 50 bytes	Low	Manufacturing - Delivery
2D barcode	No	Yes	16.9-21.7cm	1556 bytes	Low	Manufacturing - Delivery
RFID	No	Yes	6.5-16cm	4000 bytes	High	Manufacturing – End product

Compared to 2D barcodes passive RFID tags possess shorter read range, but the increased storage, durability and lifecycle are major benefits. RFID tags can be left inside elements, which can be used in other applications later in the project's lifecycle, like building quality management based on pre-placed RFID tags (Ko, 2009). Radio-based methods can improve process efficiency by allowing all identification and logistics data to be processed digitally. Radio-based methods do require some external devices and can place extra demands on workers. However, if supported by relevant information systems, the radio-based methods can ease automatic data processing and thus making the process as a whole more effective.

RFID has advantages over barcodes in three areas: Its suitability to rough environments when embedded in concrete, larger data storage capacity and reliability (Kallonen and Porras, 2007). The use of RFID is growing in different fields of engineering and construction industry, because of its advantages in automated tracking (Sarac et al., 2010; Sardroud et al., 2012). Its major drawbacks are higher costs per tag and the lack of wide support in existing infrastructure. However, the advantages in the use of tracking have clear benefits and RFID-based tracking systems should see wider usage in the future (Sardroud et al., 2012). A case could be made for organizational inertia playing a large role, because utilizing RFID in the management of construction materials requires several new support systems both through the entire logistics and at the construction sites.

3. DIGITAL LOGISTICS MANAGEMENT

Identification of building blocks is not very useful by itself. The real value of identification can be utilized by connecting the concrete elements into data items in design models and production plans, and by providing additional and updated information to these systems throughout the supply chain. During its lifespan an element passes numerous work phases and action points that can be considered as element states. A typical lifespan of a completed concrete element from element factory to installation on site is presented in Fig. 4. The work phases at the concrete element factory include inspection, moving to storage, and loading for transport. After transportation of the elements to the construction site, the phases include acceptance/reception, possibly temporary storing at the site, and finally installation of the element.

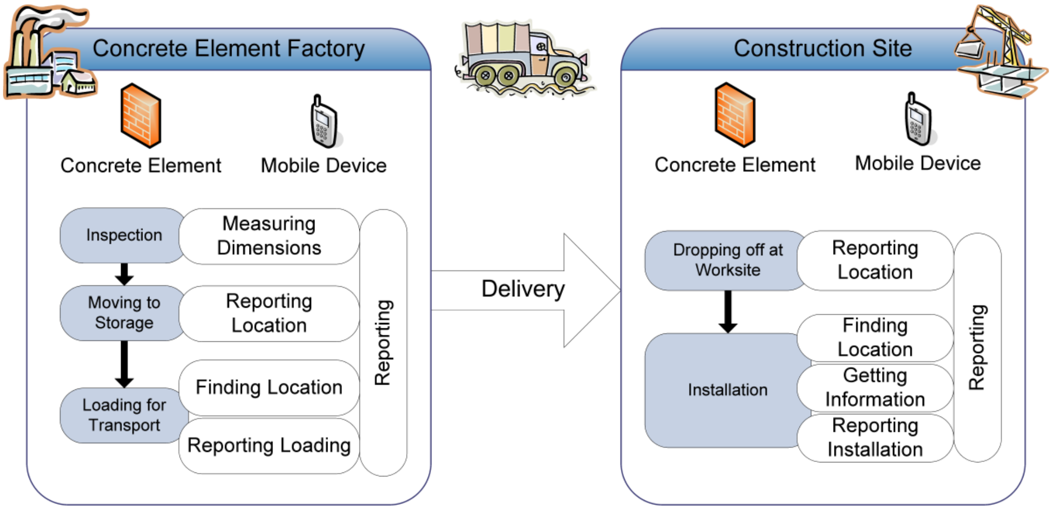

FIG. 4: Tasks involved in different phases during the lifespan of a precast concrete element

Information about element states is valuable not only for the company directly involved but also for other partners in the project. To be able to share this information efficiently two requirements must be filled: accurate information has to be produced systematically, and information must be easily accessible to all parties involved and their information systems.

Someone is, or at least should always be, responsible for documenting the prescribed actions at the construction yard. Individual events are traditionally written down on a piece of paper and at the end of the working day these events are registered into information systems or a diary. This naturally causes a lack in information sharing and also double work, since the same information and notes are typically handled manually more than once. To ease information production and communications thus producing real-time information, mobile devices are a good choice for on-site data collection, and for information management, the use of a centralized system as a gateway from mobile devices to enterprise information systems is advantageous.

Because of the importance of accurate and current data in logistics, the use of project information management system in logistics has been a target of numerous studies (Angeles, 2005; Ergen and Akinci, 2007; Leung et al., 2008; Shin, 2009; Strachan, 2009; Yin et al., 2009). Different approaches to the use of the systems in construction logistics have been examined. There have been approaches that use an online web system (Kaneko et al., 2007), a mobile device based system (Wang, Lin, et al., 2007) or both (Yin et al., 2009). All reported successes in improving the logistics chain performance. In the following subsections we introduce the design of our logistics information management system, which combines positive aspects from earlier studies into a single, comprehensive system and introduces automatic, mobile device based element management as a novel aspect.

3.1 Information management system design

When sharing information between partners, a common communication practice has to be agreed. Our solution is to transfer the information produced into a centralized information system that can be used to both share and even analyze the information. The system works as a gateway to connect the mobile users using mobile devices and the various information systems used to manage the construction project information. It can be thought of as a middleware system that collects and facilitates the transmission of construction site element information between different software components and users across the entire project. The information system architecture and its different components are presented in Fig. 5. Different sensors and mobile devices produce current information, which is transferred wirelessly to the central information system, where it is processed. This information can be combined to produce reports, quality management status or accessed in different services for visualization. In addition to inbuilt services, the project partners are able to access the gathered information through a centralized gateway thus making information exchange more transparent. For example if the construction site data was initially imported from BIM software, the updated status of the construction elements can be transferred back to the model as the construction progresses. Accessibility to information is improved compared to practices where the data is transmitted only by manual report, such as emails or phone calls.

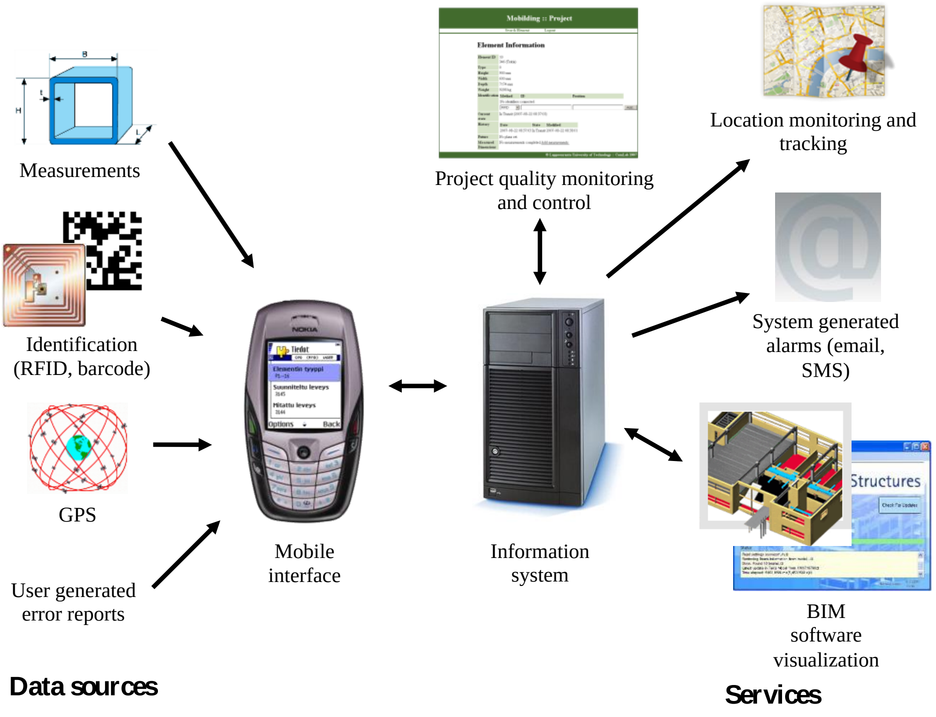

FIG. 5: Information system architecture.

3.2 Information system

The information system consists of a database, which holds data related to the project, workers, partners, individual construction elements, quality problems etc. The main purpose is to bring together project-related information, so that the information is easily accessible to project partners. Data is stored for future needs and management purposes, such as long-term performance tracking to improve project processes and produce reports.

The information system's software stack is composed of various freely available server software packages. The different levels of the software system are presented in the Fig. 6. The main intelligence and data processing is handled in the PHP software layer. It processes the communication requests from different types of clients and accesses and combines the raw data from the SQL database. The information system acts as middleware, so it must offer connection capabilities for several different types of clients. This version of the system provides three different methods of connections, but the base layer has been designed to be extensible, so new kinds of connection servers can be implemented in the system at a later date. The three different client types are Tekla Server, which is the BIM solution used in the pilot projects, mobile devices with a data entry client and a web server for desktop access. They all require different connection protocols, because of their different implementations and data access needs. The Tekla Server software and the mobile device connect through XML-RPC and SOAP web service protocols, with part of the data processing and all of the presentation processing being handled in the client. The web browser interface uses a more standard web service and HTML markup data is transmitted directly in viewable form to the browser. The service designs are presented in the following subsection 3.4 and practical tests in the following case outcomes section.

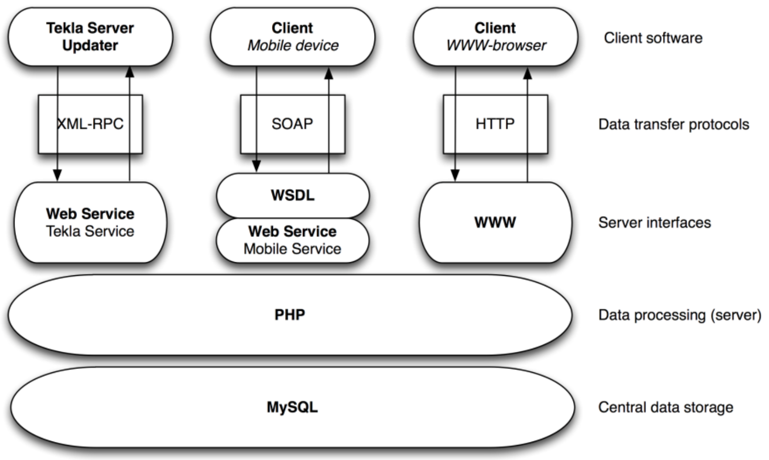

FIG. 6: Information system software stack

Data to the service is gathered from different sources. In the initial stages of a construction project data is normally imported from a BIM (Building Information Model) application, with the possibility to establish two-way communication with the BIM system. The imported data can consist of information about concrete elements of the project including dimensions, drawings, and the timetable of major actions. Identification in the virtual model has to be connected to real world items, which requires that identification from the virtual model be attached to the item as a label, barcode or a tag. In addition, there is a need for user management both at company and individual level to guarantee that only the permitted users have access to the information.

One of the basic operations in a multiple operator supply chain is to update the system to reflect the state of items in the field, e.g. during installation. State updates create a history or a life cycle for each item, which can be used, for example, in a case of error to specify how the error might have happened and to improve the process. If a user notifies an error, he can use the system to create an error report, which is immediately reported in the system. The system can then automatically notify pre-defined persons. The system can also import data from other sources, such as GPS (Global Positioning System) location information as part of the item state information, or if the user completes digital dimension measurement of an item, the system can warn if the dimensions do not match the plans.

The system and logistics chain partners can follow the project in real time as data is updated when there are changes. An example of an update is production of a precast element, which will change the state of the element. Partners can access the information through a web interface or the gathered information can be exported to their systems such as back to the BIM application. Consequently, the original model can be constantly updated to reflect the current situation of the construction project.

3.3 Mobile end-user device

There is often a need to produce information on site and in locations where there is no access to desktop applications or web interfaces. Therefore, mobile phones have been used as end-user devices in our pilots. The advantages of these devices are that they provide a wireless communication link, are flexible to use in most locations, are rather small, and people are accustomed to them. In order to increase the automation of data collection, the capabilities of the mobile phones were extended by connecting peripherals through the Bluetooth-interface. The implemented mobile application supports an RFID reader for identifying the concrete elements, a GPS receiver for positioning, and a laser dimension meter for measuring the dimensions of concrete-cast elements. The mobile phone and some peripherals used in our pilots are presented in Fig. 7. Some of the presented devices can be integrated into a modern smartphone device, but a traditional number keyboard has the benefits of being used in more severe weather conditions that require the user for example to wear gloves. Peripherals can also have advantages over integrated devices: An external GPS locator can use an external antenna for more accurate positioning and an external reader can be more robust or easy to handle. Additionally external RFID readers support a wider range of frequencies and stronger transmission power than readers integrated into smartphones.

FIG. 7: Mobile phone, RFID-reader, GPS receiver and laser dimension meter.

Even though mobile phones are not constrained to a fixed location, they have some restrictions. Limited memory, processing power, and disk capacity do not generally cause difficulties but challenges are more related to usability and accessibility. Wireless networks are prone to disconnections and variations in data transfer rate, and battery-powered devices rely on a finite power source (Satyanarayanan, 1996). Since mobile devices are designed to be easy to carry, they are made as small and light as possible. This limits not only the battery size but also screen and keypad size, creating challenges to design usable and still efficient applications. Conditions in construction sites are typically harsh, which requires either durable devices or careful usage of devices.

When employees use personal devices, each user and completed action can easily be linked to each other. This may have both a positive and a negative effect. It can be used to provide additional information and to guide an employee when he is completing his tasks. On the other hand, workers may feel that the employer is keeping them under surveillance and their actions and work are being constantly monitored. Nevertheless, personal devices can make information registration more effective and makes it possible to contact the right person if, for example, additional information is needed.

3.4 Services

The information system itself does not provide any services to the user, but instead a middleware layer through which different end user services can be provided. Three different end user service interfaces were implemented as a part of the research project and the system is designed to be further expanded if necessary. Different services are exposed to the user depending on the projected need of the user and the limitations of the interface.

3.4.1 Mobile device data entry application

A mobile application was developed to allow the concrete element data to be collected and accessed at the worksite. Based on interviews with construction industry professionals, mobile phones were considered more suitable in rough environments than touchscreen smartphones, because the button-operated phones were considered physically more durable. Mobile phone networks provide wide coverage without a need to build new network infrastructure, and data transfer rates have seen significant improvement with the arrival of third and fourth generation (3G, 4G) networks. In addition to manual data input, the mobile program can identify the location of data entry automatically and with the peripherals it can record other information about the element, like automatically measured dimensions or photographs. Based on interviews the following use cases presented in Table 3 were identified and a selection of services was designed to address the use cases.

TABLE 3: Mobile phone user services

Use case	Service	Description
Read RFID tag	Concrete element identification	The user can read a RFID tag and identify the exact element based on its identification.
Enter new tag data	Concrete element identification	If the tag is not found in the system, the user can enter the details for a new element.
Send status update	Concrete element and logistics chain status management	After identifying an element, the user can update its installation status.
Fetch element data	Concrete element and logistics chain status management	After identifying an element, the user can view the stored data about the element.
Update element data	Concrete element status and quality management	After identifying an element, the user can update its data. For example entering exact measurements.
Report quality issue	Concrete element quality management	After identifying an element, the user can report quality issues. The user can also attach recorded voice reports or photos to avoid slow text entry.

The main use for the mobile application is to service the immediate data entry needs that come up when installing or inspecting new elements. The Fig. 8 shows the screen-by-screen progress of the send status update use case, where an element is marked to be installed to a specific place in a building.

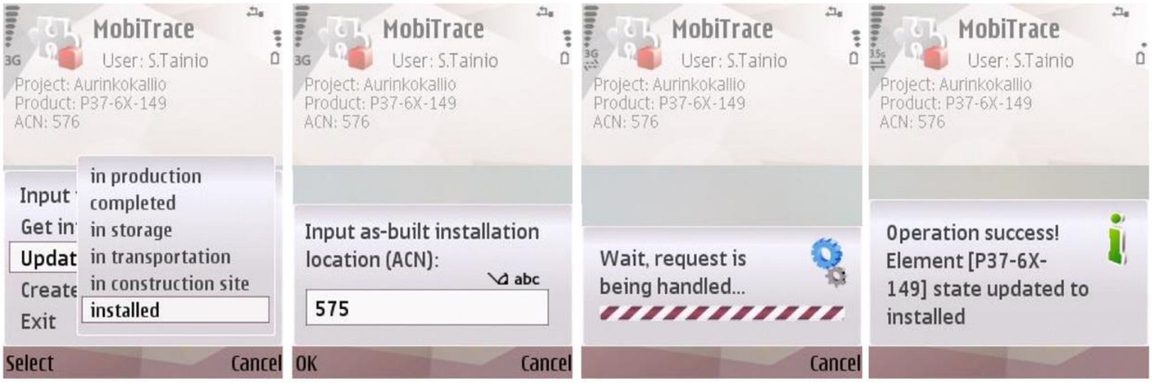

FIG. 8: Sending installation acknowledgement to the information system from a mobile client.

3.4.2 Element status web application

Desktop users can display a wider range of data than can be displayed with mobile devices and with larger screens it's easier to manage larger amounts of information. A web-based management interface was implemented for administrative and management personnel. This web interfaces enables multiple users in diverse locations to monitor concrete element chain locations, track quality issues and see installation progress. In essence the user can gather, process and produce reports based on the information input from various mobile devices that are used at the construction sites. The provided web interface services are detailed in the Table 4.

TABLE 4: Element management web interface services

Use case	Service	Description
Display project progress information	Project management statistics	The user can see overall progress statistics of the project. For example the amount of installed concrete elements.
Search and display concrete element status	Element status management	The user can search for and see all the data associated with a single element.
Update concrete element status or metadata	Element status management	The user can manually change the element status if necessary.
Add new elements or remove replaced elements	Element status management	If elements are lost or new elements are added manually, these updates can be also done at the web interface.
View quality management information	Quality management	All quality management events and reports can be sorted, selected viewed.
Process quality management information	Quality management	The status of reported quality issues can be changed as they are being processed or additional details can be entered.
Display project statistics	Project management statistics	Overall project statistics can be viewed and exported as graphs. For example quality issues remaining or quality issues detected per day.

The element location, logistics status and quality management data that has been gathered with mobile data entry devices can be collated and inspected with the web application interface. The quality issues can be examined as percentages or processed error by error, so that the project management can address each report and for example create new work orders. A sample error report is presented in Fig. 9, where a user has reported surface damage in one of the elements and added a photo of the issue.

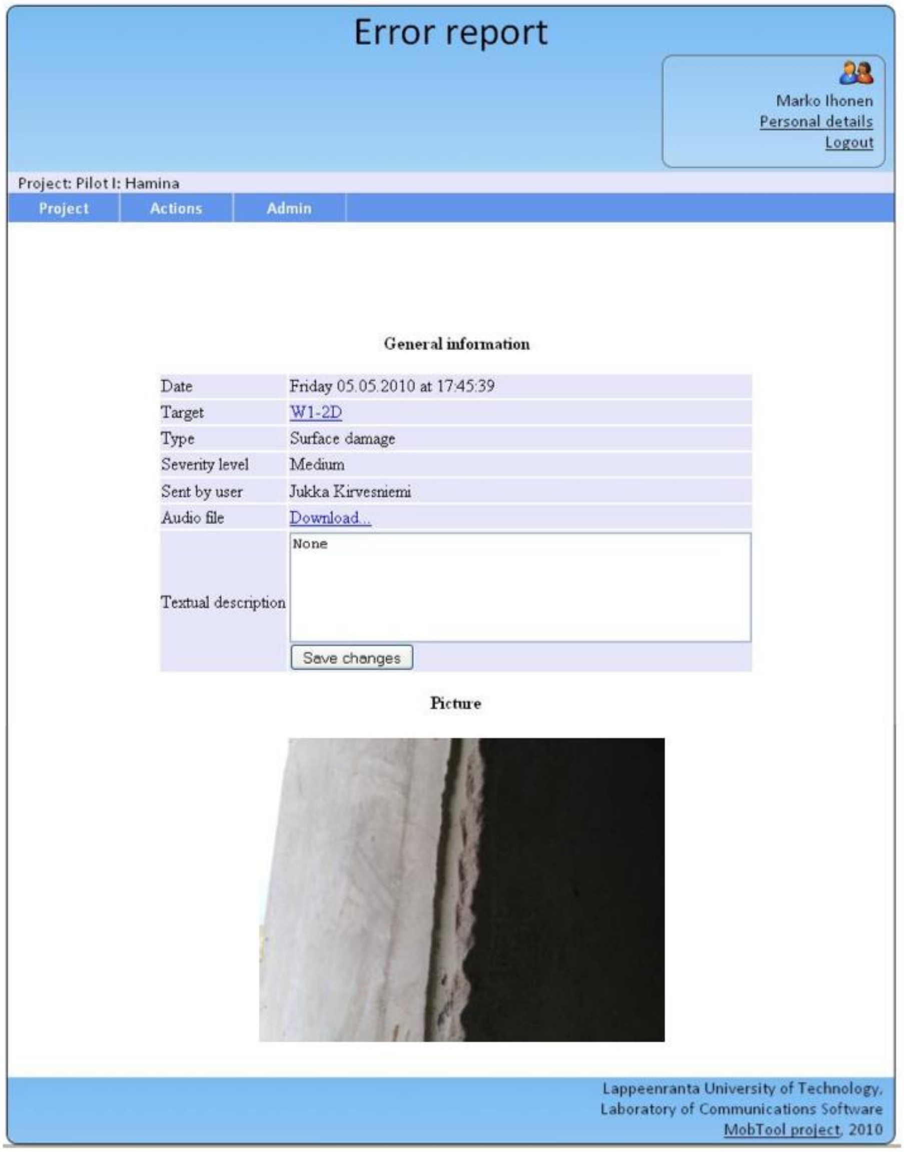

FIG. 9: Web application displaying a concrete element quality issue report

3.4.3 BIM Software Bridge

The information system provides software system interfaces in addition to direct user interfaces. One of these available interfaces is the two-way communication bridge to the BIM software. With the BIM software the user can see visual presentations how far the construction process has progressed, with colors highlighting the status of individual elements. The 3D-model of the site presented in BIM allows a more accurate visualization than would be possible with web-based lists or printouts. With it one can see what the current situation is and with the help of other services one can find out the underlying reasons for delays, like for example an uninstalled part, which was damaged while in transport. All services that can be provided through the BIM bridge in the BIM application are detailed in the Table 5.

TABLE 5: BIM Software Bridge services

Use case	Service	Description
Export all elements from new project to information system	Bidirectional import-export layer between BIM software and the information system	The information system can use a BIM project as a part of the initial project setup. The building structure is defined in BIM and then all the details are imported to the information system.
Synchronize BIM project with the information system	Bidirectional import-export layer between BIM software and the information system	Changes made either in BIM or the information system are propagated to the other side of the connection.
Change translation settings	Translate concepts between BIM and the information system	Certain elements field need to be translated between the system and the bridge contains a translation table.
Generate ACN numbers	Translate concepts between BIM and the information system	The bridge can generate and associate unique identification numbers for both the information system and the BIM model and then translate between the two numbering systems.

While the software bridge itself doesn't provide a lot of functionality, it really doesn't need to. The used 3D BIM software can be used to design entire buildings to the detail of every last metal bar and screw and with the import-export functionality this very detailed data can be imported to the information management system. A typical view of an example use case of the BIM software is presented in the Fig. 10. The model of the building is connected to the information system and the user can examine the installation status of the elements in a three-dimensional presentation of the building.

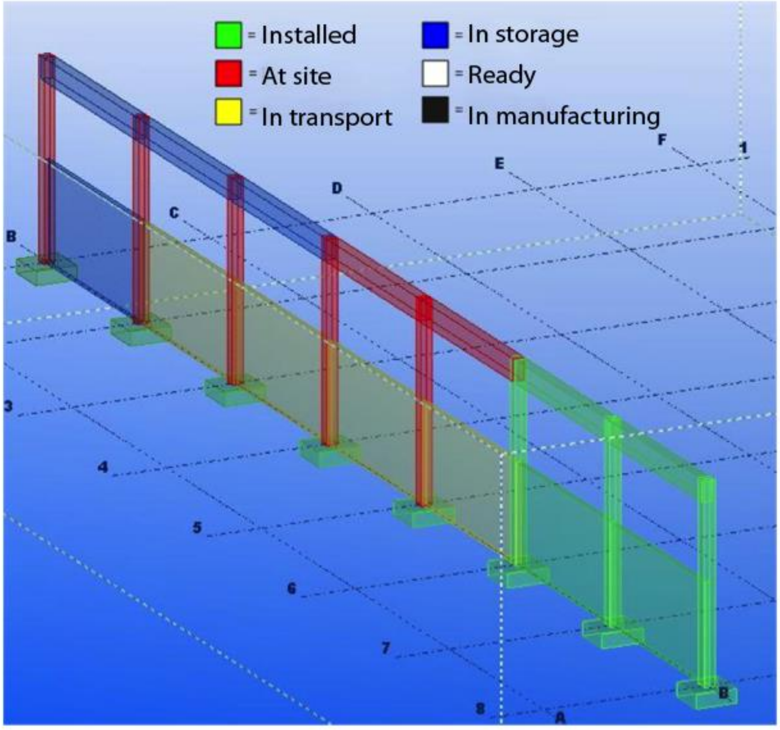

FIG. 10: Wall section's installation status presented in the BIM software

4. AN APPROACH TO USING MOBILE TECHNOLOGY IN THE CONSTRUCTION INDUSTRY SUPPLY CHAIN

The research project was carried out in Finland with several cooperating construction industry companies. The goal for the project was to establish how information can be managed from planning and object construction to the completion of the building. Cooperation partners' need for information and the use of mobile devices for information creation forms a cornerstone of the management of the whole process.

The research group developed a technological approach and implemented it to respond to the need of the collaborating industry partners, who together represent a major area of Finnish construction industry and include some of the most notable construction companies. The pilot projects that comprise the case study were done at the partners' construction sites. This allows the targeted part of the system to be used in a realistic environment with a full logistics chain reaching from production to a finished building.

4.1 Research setup

The system was first implemented fully according to presented plans before being tested out in practice. A case plan was drawn out to test different aspects of the system in separate construction project pilots, with each pilot designed to test a different aspect of the system. The research was either performed at a construction site or in a test laboratory, depending on the level of the test. Most of the research was performed at the construction site, because one of the main focuses on the research was testing the practical applications and implications of the implemented services.

The implemented system was tested first in laboratory tests and then during three construction project pilots as a case study of using mobile devices in the construction supply chain. The tagging process and the usability of RFID identification were fundamental to these pilots. Each of the pilots had separate technological goals. The first pilot was carried out to gain experience of tagging as a part of the casting process. The second pilot evaluated information quality by measuring the elements using a laser dimension meter and comparing those values to the planned values. The third pilot tested technological aspects of the positioning of elements in the element factory yard using GPS to provide the coordinates for each stored element. Results and details of experiments conducted in the pilot projects are presented in the following subsections. The Table 6 shows the specific focus and the location of each of the pilot projects.

TABLE 6: Case pilot phases

Pilot	Logistics focus (element lifecycle)	Technology focus	Location
1st	Laboratory tests of technology	Embedded RFID in concrete elements	Research team laboratory
2nd	Manufacturing and construction (early, late)	Field test of RFID in concrete elements	Concrete element factory, construction site
3rd	Inventory (middle)	Assisted measurement in quality control	Element storage facility
4th	Inventory (middle)	Locating elements by GPS	Outdoors storage facility

In the first phase different RFID technologies were tested for their utility in embedded concrete. In the tests different types of tags were embedded at different depths in precast concrete elements. These elements were then tested in a series of simulated weather conditions and were submerged in elements commonly encountered at construction sites, like water and ice.

The second pilot is designed to gather practical experience about RFID tag installation in a real use-case scenario, with the tags embedded into the elements at a factory construction line. During first tests and in earlier studies the HF RFID frequency range (13.56 MHz) proved most suitable for concrete embedding (Kallonen and Porras, 2007). Therefore, a selected slim credit card sized (53.98x85.60mm, defined in ID-1 of ISO/IEC 7810 standard) Philips BC ISO15693 RFID tag carrying a 64-bit unique identifier was chosen for the rest of the pilot projects. The research target of the pilot is to show that the initial findings of reliable RFID installation and identification with concrete elements can also be applied to field conditions.

The third pilot concentrated on the assisted measurement of element dimensions and the process of automatic transfer of those measurement results to an information management system. It was performed at the element factory warehouse, where the construction elements are temporarily stored before being moved to the construction site for installation. The research target of the second pilot is to measure how well the tagged elements in storage can be identified and measured for the information management system. Additional goals for the second pilot are how the verification of measurements and the software system's work direction affects the quality control process.

The fourth pilot concerns locating elements and transferring the location data automatically to the information management system. In some factories, elements are stored in large outdoor storage yards before transportation to the construction site. In locations like these, it can be a challenge to find a set of elements to be delivered even if the yard is divided into smaller areas and is slot coded. Similar complications exist with intermediate storage in construction sites. In the pilot project we tested our approach to solving the issue, which is use of GPS to ascertain the positioning of elements in an outdoor yard and the sharing of this information in real-time using our information system.

In all of the pilots the systems needs to be preloaded with information about the elements. Element information during the course of a construction project is stored in several different places. Buildings are typically modeled with design software, element factories have their production planning systems and other parts of the logistics chain have their own, local storage systems. Importing element identification directly from the electronic design model was considered most desirable, because that allows automatic, accurate retrieval of data about the designed building. An interface was implemented that allows the project information management to import identifiers, dimensions, information about scheduling and completed actions and export them back automatically. In two of the pilots, information about the elements was imported from a BIM (Building Information Model) application.

The overall goal for the series of the pilots is to test the tracking system in a functioning industry logistics chain and to produce information based on a functioning production facility and a construction site. Another goal is to gather industry-based data for the information management system services and test them in various scenarios at the construction site. The BIM synchronization can be tested as well on the construction site's building model to see how frequent updates can be applied.

4.2 Pilot projects

4.2.1 Pilot 1: Laboratory tests of RFID readers

The first pilot concentrated on testing the basic technologies involved in the laboratory, where different environments that occur in the field were simulated. To ensure the functionality of existing RFID solutions and the related communication standards in this field, a series of tests in varying environments were completed with authentic materials. The tested solutions were based on passive ISO 14443 (HF, NFC), ISO 15693 (HF) and ISO 18000-6 (UHF) standards and frequencies.

Near Field Communication Tests

Near Field Communication (NFC) is a short-range two-way communication technology based on existing RFID standards (ISO/IEC, 2004). It operates at 13.56 MHz frequency using inductive coupling and can be considered a subset of RFID technology. NFC enables more diverse communication modes compared to a traditional RFID reader / tag combination. Two NFC devices are able to communicate with each other and NFC devices are capable of emulating RFID smart cards. The main application areas of NFC technology include contactless payment, accessing digital content (smart posters etc.) and connecting electronic devices. An increasing number of mobile phones and tablet devices have integrated NFC.

To ensure the operability of NFC tags with mobile phones we carried out tests with the MiFare Standard 1k tag. The power output in integrated mobile phone NFC readers cannot be adjusted and is typically under 15mA. Results indicate that when the smart card is perpendicular to the antenna, the maximum reading distance is approximately between 2.5 and 3 centimeters from the NFC antenna. A wooden substance between the tag and the antenna did not have an effect on the read-range, but metallic substances prevented reading altogether. During a series of tests, the NFC technology proved to be reliable and sufficiently fast, taking less than a second, for the identification and transfer of small amounts of data adequate for our scenario.

One of the virtues of an NFC enabled mobile device is that the same device can be used to both identify construction elements and process information related to the elements. Even though NFC-equipped mobile phones can be used to read RFID tags, the short read-range sets constraints on attaching NFC tags to construction elements. To be readable with an NFC phone, RFID tags would need to be placed very close to the surface of the element, which could result in a weakened surface structure. Because of the very limited reading range, the tags in pilots and applications completed by some companies have been attached to exterior labels to ensure the reading process. This, however, shares the same disadvantages as visual labels: they can detach, and the life cycle of the identified tag ends when erecting the element at the latest. To enable the reading of tags embedded inside concrete elements, more efficient external devices are needed (e.g. a handheld reader with a larger antenna).

High Frequency Tests

The next step in our tests was to establish the usability of ISO 15693 high frequency tags. HF operates at similar frequencies as NFC, but uses different communication standards. It is not commonly embedded in small devices, uses both heavier and more powerful equipment and is more commonly seen in industry rather than in end user devices (Kallonen and Porras, 2007).

The tests were completed using two basic ISO 15693 compatible passive tag models, and a handheld USB-reader with an antenna of exterior dimensions of 80*90mm. The transmission power of the reader was 500mW. The size of the square tag is 60*60mm and the diameter of the round tag is 45mm. In this test the tags were embedded at a depth of 40mm inside the material in question and the maximum read range from the material surface was then measured. Our tests and other research gave us an idea of how the technology could be used in the construction industry in practice, especially when embedded inside concrete elements. Firstly, the read ranges were tested in free space as a reference, after which the tags were embedded into three different substances: concrete, water and ice. It was thus possible to establish the potential of tags in harsh real-life conditions.

Reading of the tags proved to be reliable through all the materials used in the tests. Maximum read distances attained are presented in Table 7, where the read-distances are combined distances through air and the material in question. The longest read range was achieved in open-air measurements as expected. The material in which the tags were embedded did not affect the read range dramatically. The read range was shorter, but reading was still possible at a reasonable distance, and reading proved to be reliable. Water seemed to have the most significant effect of the materials tested.

TABLE 7: Successful read distances in millimeters through different materials.

Tag / Condition	**Air**	**40mm concrete**	**40mm water**	**40mm ice**
Round Ø 45mm	80mm	75mm	65mm	75mm
Square 60x60mm	160mm	130mm	110mm	150mm

The tests illustrated that reading HF RFID tags is possible even if the tag is embedded inside a concrete element. Reading can be performed successfully if the tag is embedded at a depth of no more than 4-5 centimeters. Based on the tests, it can be assumed that reading can be performed successfully even if the element is wet or covered with ice. The best results in concrete embedded RFID tags were achieved using passive HF frequency tags and reliable results were achieved in varying weather conditions. The achieved reading distances were from 6.5 to 16 centimeters, depending on environmental conditions, when embedded 4cm deep in concrete. This approach was chosen for use in the pilot projects.

Ultra High Frequency Tests

RFID systems using Ultra High Frequency (UHF) use an electromagnetic field, generally in frequencies between 866-956MHz, to transmit energy and data between the tag and reader (Rao et al., 2005). It has been seen as an optimal solution in logistics because of the longer read ranges compared to HF. With electromagnetic waves the effects of the environment are however more severe than with inductive coupling since the environment affects the frequency on which the tag's antenna responds. This phenomenon, called detuning, makes it more difficult to read a tag's content and can even render the tag useless with the selected reader and frequency.

UHF signals cannot penetrate metal or water, which can make the use of UHF tags difficult when embedded into certain products. Foster and Burberry (1999) have completed measurements using UHF and microwave tags attached to different products and materials. They concluded that directional antennas are a much better choice than omni-directional antennas because of fewer disturbances to the radiation patterns and lessened return loss. Griffin et al. (2006) placed UHF tags on different materials and measured gain patterns. The measured gain patterns show significant distortion due to the permittivity and loss tangent of the material, surface waves, and diffraction. The effects of metal and water placed near UHF RFID tags were studied by Dobkin and Weigand (2005). They concluded that the most important reason why read ranges shorten near metal or water is the decrease of the electric field near the surface of the objects. Detuning is significant only when the tag is very close to the object.

Embedding of UHF tags causes major difficulties and not too many implementations have been realized. Ukkonen et al. (2006) have used UHF RFID tags in identification of paper reels. When embedding a UHF tag, the tag needs to be specifically designed for the product and material in which it is to be placed. The design must take into account the material in which the tag is embedded as well as other parameters, such as depth of installation. Since the environment has much less effect on HF tag performance, HF tags are usually preferable for use in difficult surroundings, especially when tag contents need to be read through different materials.

Lately UHF has been considered as a solution for item-level identification. Therefore, alongside our HF tests, UHF tags were also tested to compare the results and usability for construction industry needs. One handheld UHF reader and two fixed UHF readers were evaluated. The maximum transmission power that was used in tests was 2W ERP, supported by the fixed readers. It was possible to read tags embedded near the surface of the concrete element easily with fixed readers, but when using a handheld reader at its maximum supported 500mW transmission power, reading an embedded UHF tag was nearly impossible. For the application under consideration, this finding makes the use of UHF awkward since reading of tags should be possible in several steps of the supply chain and mobile use should be supported.

After performing the tests with all the three communication technologies it was concluded that the HF RFID technology is most suitable for the use of embedding in concrete, because of its longest range and readability in various weather conditions. The laboratory tests suggest that HF tags can be successfully embedded in precast concrete and the read distances are adequate for uniquely identifying the elements in even challenging environmental conditions.

4.2.2 Pilot 2: Concrete element tagging and identification

The second pilot was arranged to gain knowledge on concrete element RFID tagging process and practices. All the used tags were embedded in the concrete elements during the casting process. Since the tags did not have fasteners, they had to be either embedded about two centimeters below the surface on the upper surface of an element or in some cases pushed into the side of an element. The tags and physical 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. The tags were delivered to the casting site and employees were responsible for finding the appropriate tag for each of the cast elements.

The pilot was made in two parts. The first part was carried out with concrete pillars. A building containing more than 100 pillars and was divided into three segments. In the selected segment all 36 pillars, which were of 8 different element types, were tagged. The tags on each of the “long-shaped” pillars were embedded into a defined location to ensure that they could be read without using external instruments when erected. In the planning and manufacturing phase the element factory identified each pillar with unique RFID serial number, but at the construction yard only the element type was considered; unique identifiability (item level) was not required. Maintaining the traceability of each element was considered as one of the challenges. The divergence between the plan and realization has to be updated in the as-built model when similar but uniquely identified elements are erected into each other’s installation position.

The second part of the pilot consisted of tagged façade elements, which were all unique. Confusion between elements was therefore not considered as a problem in these cases. Since the information was exported from a production planning system, not a design model, it was not possible to verify the installation spot of the RFID tags to ensure that there would not be obstacles in the finished building blocking the reading. A compromise was therefore made over the positioning of the tags. 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 at a depth of 3 cm. This position was chosen to prevent the blocking of overlapping elements when reading the tags in the completed building.

After the elements were erected in the construction sites we searched for the tags in the elements. Handling a large number of elements identified by type, not uniquely, proved our concerns about element disorganization arising from the first of our pilots to be justified. Not only had the pillars and elements cast for specific segments of the building been mixed with each other but a number of elements had also been mixed with elements from other segments as well. After a careful search for the tagged elements, we were able to find 19 out of 36 tags that were connected to the BIM-model and existed in our database. Eight of the missing tags had not been installed in the pillars at all because of a human error at the element factory. However, all of the tags from the façade elements were found.

A further complication was that nine tags of the tags that were installed could not be found at all. As some additional construction objects had already been installed, blocking access to the vicinity of the optimal position of an element, and our other tests have proven good readability and reliability of RFID tags embedded in elements, our conclusion is that most of these missing tags were embedded in these blocked elements. However, since the operability of each tag was not verified after casting there is also a possibility that some of these missing tags simply did not work, were installed in an incorrect and unknown position, or were installed so that reading was impossible, such as too deep in the element or too close to supporting steel reinforcements.

The pilot cases strengthened our assumption that installation and placement of tags requires general guidelines and their placement should already be considered and decided in the design phase and marked on the design plan. General guidelines, e.g. installation height and distance from the edge, help users to find tags. Examples of typical errors and a suitable placement are given in Fig. 11.

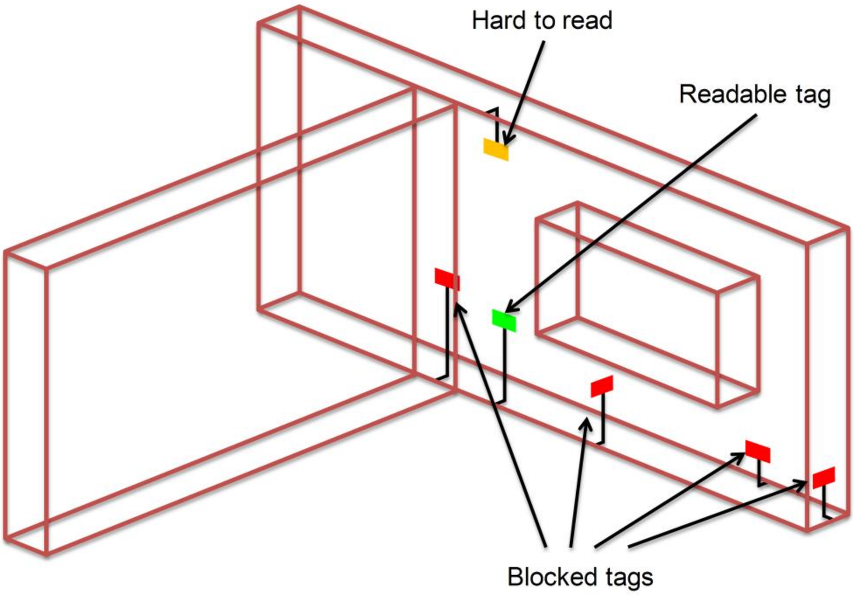

FIG. 11: Identification tag placement consideration.

The main conclusions from the pilot were that placement of the tags should be defined in the design model, so that they are accessible. This means that the process for embedding tags in the element factory has to be used as early as in work plans and all the elements should be tagged. The pilot showed that the embedding process for the tags works and the embedded tags are readable. Trial with pillars showed the importance of defining the tag places in the design model.

4.2.3 Pilot 3: Measurement and verification of concrete element dimensions

One important step in element production is verification of the product. This includes measurement of the product dimensions and their comparison to planned dimensions. In the pilot hardened façade elements were stored in a standing position inside the element factory, as shown in Fig. 12. In this phase, we tested how a laser distance meter can be utilized to measure the dimensions of concrete elements, and how easily these values and the verification results can be passed to the centralized information system using a mobile phone. The measurements for all the stored elements were completed in this position instead of individual measurements when removing them from storage for transportation to the construction site.

FIG. 12: Dry concrete elements in the factory hall.

The measurement verification system was implemented by using a mobile phone, a dimension meter, RFID reader and a data connection to the information system. The elements of the measuring systems are presented in Fig. 13. The connection between the mobile phone and the two peripherals was established using Bluetooth. The measurement process followed the software-guided order of actions. The implemented mobile application first requested the user to read the unique serial number of the element under inspection using the RFID reader. After identification the three main dimensions, width, height and thickness, were measured. The application also supported reading cross-measurements, which play an important role when verifying elements but was not utilized in this pilot. After the verification process of a single element was completed, the results were sent to the information system using a data connection.

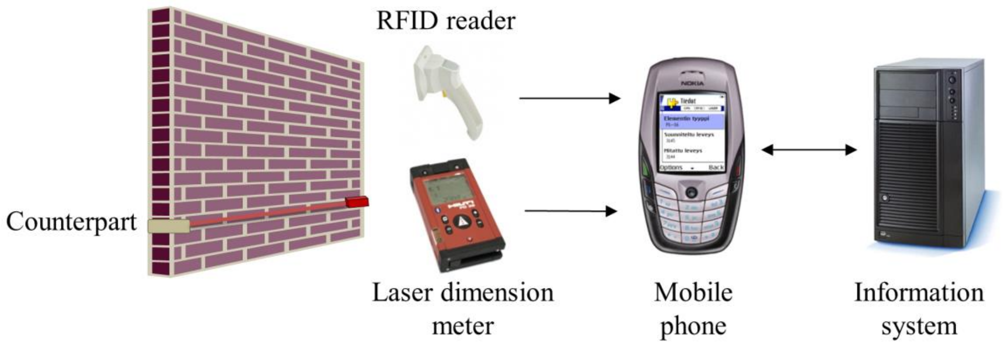

FIG. 13: Laser dimension measurement system for concrete element.

The measured values were automatically compared against the designed values imported from the BIM or production management application. The employee doing the measurements with the mobile device at the factory was informed about successful dimension verification and notified if the difference between designed and measured values exceeded the defined tolerance values. Expected and measured values were shown during the measurement process, as presented in Fig. 14. Consequently, the employee was immediately able to see if the results differed too much and was able to redo the measurement before sending the values to the information system if there was suspected human error in measurement.

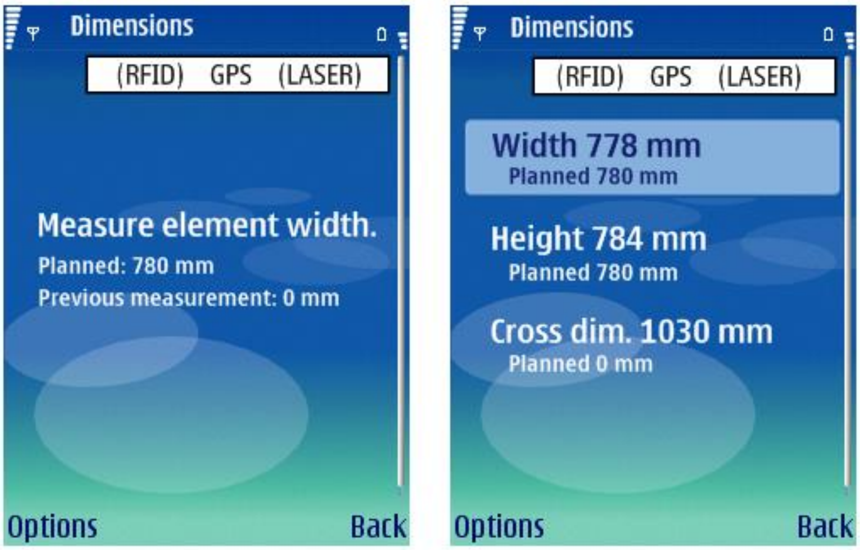

FIG. 14: Screenshots of dimension measurement application.

One issue arose during the pilot: One of the elements could not be measured because of the placement of the elements side-by-side. Therefore, it was neither possible to identify the element using RFID or measure the dimensions. This problem can be solved by either measuring the dimensions before placing the element on the rack or by placing the elements so that the RFID tags remain readable when the elements are in the rack. Feedback from employees suggested that the elements should be measured before placing them in the rack because usually there is little space to complete the measurements. One of the goals of the electronic measurement system was to overcome bad practices. These practices included problems like writing down specification values instead of measured values or just marking “ok” when values were inside tolerances.

4.2.4 Pilot 4: Outdoor positioning of elements

In the factory in which our application was tested the hardened concrete elements were transferred to the outdoor storage yard and stored side-by-side in a standing position. A GPS receiver was used to provide information about the element location and RFID was used for identification. The equipment for the task is presented in Fig. 15. Position data was bound with the element identification number and transmitted to the information system at the time the elements were stored at the yard. In addition, the element state was automatically changed from “in fabrication” to “in storage”.

FIG. 15: Equipment used in this pilot.

As the storage coordinates were stored in a database, workers were able to establish the location of products using a web-browser. Both a list of elements and an image of the positions were provided. An image of the storage yard giving the slots and the stored elements is presented in Fig. 16. The map can be used for example as an attachment in a docket, offering drivers additional help to find selected elements in the storage yard.

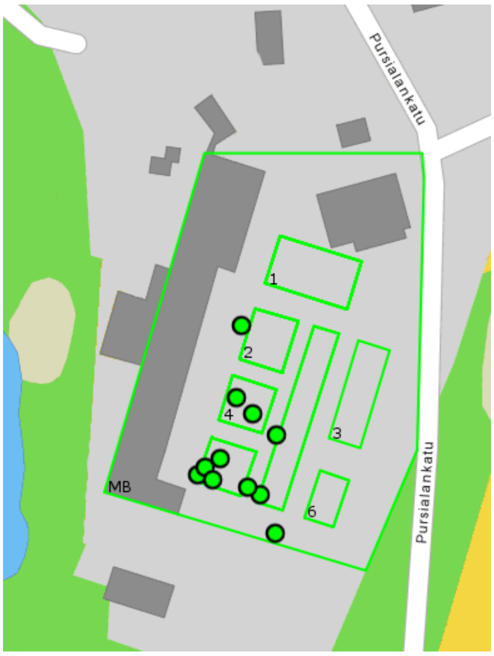

FIG. 16: Storage yard of an element factory divided into several user-defined slots.

In addition to GPS coordinates, the identifying mark of the storage slot was stored in the database, which in our pilot had to be chosen manually by the employee. This information was later used to analyze whether the GPS coordinates and manually input area matched with each other and could hence be automated in the future. If the GPS is not used for some reason, the slot information could be used to locate an element, although in this case the provided information is not that precise and requires more human interaction.

After the storage phase, the elements were delivered to the construction site. When the elements were loaded onto the truck, each element identification number was read and the status of the elements was changed to "in transit." This helped to keep the inventory up to date and provided additional information for other parties involved in the project.

The greatest problem in this pilot was the delay in receiving GPS coordinates. Because the GPS receiver was turned on just before using it, to save the battery, it occasionally took up to a couple of minutes to get the coordinates. This is definitely not an acceptable delay and can be fixed by using AGPS (Assisted GPS), which speeds up the GPS startup dramatically. Another issue was the number of devices. Carrying a mobile device, GPS-receiver and RFID-reader made the usability quite weak. This can be improved by using a mobile phone that has an embedded GPS receiver. Even if separate devices were used in this pilot, they can be embedded in a single device, for example the phone's internal GPS receiver. However, embedded devices might have more limited options, e.g. internal RFID and GPS devices rarely have connectivity options for external antennas and have less transmission power.

4.3 Pilot project outcomes

During the case study it was shown that elements are reliably identified when a necessary number of tags are used per element and when the tag placements are predefined. Because tags are very affordable when bought in bulk, embedding several tags per concrete element is not a problem. Having reliable, long-lasting identification methods will make tracking more reliable through the logistics chain and can be item specific. More specific identification methods can make quality management information factory and production line specific, both during transportation and after installation. The information can also be exported back into a BIM, allowing management personnel to see exactly which element was installed where. Previously such information would eventually be lost and the precast elements would not be identifiable after the installation process.

Identification in itself is not enough in some cases, because large sites can have many identical elements stored over a wide area. Going through each of the elements one by one would be impractical and new construction locations might not have a storage grid or some other mapping system prepared. A hand-held mobile device equipped with GPS and RFID automatically stores the element location in the information management system. That way the logistics status of both the site and the element is updated online instantly. Not only locating and retrieving the element is more efficient this way, but also with the help of the system the status of the storage site can be tracked in real-time.

The information management system would not necessarily improve the data management, if they provided just an alternative to paper-based data entry. The end user devices provide options for direct connections for measurement peripherals, like the laser dimension meter, where the mobile device directly relays the measurements. This way the time-consuming data entry phase can be bypassed and avoiding manual entry of keys also eliminates the human error involved. The system also has options for photograph-based quality management issue error reporting and can record voice input.

When digitized information about the elements has been produced, it can easily be shared among cooperating partners in the project using the centralized system approach. Just providing the construction site manager with exact element dimensions does not necessarily provide great added value. With the help of the system the progress data can be made available through the service interfaces to mobile devices, desktop clients and the planning personnel's BIM software. The most important information required is whether the element is built and ready and whether it is within the tolerance limits, or the tolerance and status information in other words. The greatest benefits that exact dimension measurements provide to the element factory are the digital quality verification database, trend analysis possibilities, and the opportunity to react to potential errors immediately, thus saving repair costs.

5. DISCUSSION

Completed experiments show that RFID can be used for element tracking throughout its lifecycle from manufacturing to post-installation. Element identification can solve many issues in construction logistics tracking, because precast concrete elements of the same type are externally identical and traditional methods of identification do not last for the entire lifetime of the element from transportation to the post-installation phase. The tags can be used also in other solutions, like room-level identification of buildings, as proposed in a study by Wang (2008), or to produce information for virtual building inspection environments (Sampaio, 2012) in conjunction with BIM.

In addition to proving that durable, unique identifiability is possible by embedding tags, the pilot projects produced two other major results. With unique identifiers more specific data can be produced in building planning for use in the field. Correspondingly the gathered data can be automatically targeted to the elements during the construction and manufacturing process.

Based on the pilots it can be observed that the proposed RFID-based services can enhance the traceability of precast concrete elements throughout the logistics chain. However, the sites and the construction process need to implement several, additional requirements in order to utilize the services proposed in this paper. The pilots and the information system implemented changes in the following four locations thought the logistics chain and the construction process: Planning, manufacturing, transportation and installation.

In order to uniquely record the position and the purpose of the elements, the building has to be at least partially planned and modeled in BIM, so that the role and position of each element that is manufactured and transported can be specified. The major construction corporations that participated are already starting to utilize fully modeled building sites, but not even all their projects utilize BIM. To increase the adoption of the RFID-based tracking system, the tools and services also need to become more common.

While planning requires a computer-based approach, the other parts of the chain need devices and trained personnel that can utilize the planning data entered to the information system. The manufacturing floor, the truck transport and installation personnel all need data entry devices that have the capability to read RFID tags. Previously building construction has not been a high-tech field, so training can be a significant cost in addition to the devices. In essence implementing the system provides a specific benefit in traceability, information management or quality management, but each change also requires high-tech tools or changes to the existing operating processes. The proposed changes to the precast element construction process and logistics are presented in the Table 8.

TABLE 8: Costs and benefits of changes to the construction logistics chain

Implementation area	Change	Benefit	Cost
Planning	The building is fully modeled in BIM to provide a data background for tagging and identifying elements.	The construction of the building can be tracked and modeled as the site advances. The location of issues or missing elements can be identified visually.	The construction planning requires implementation of BIM, if not already in use. Any late changes to building plans also need to be revised in the BIM model.
Manufacturing	Tags need to be embedded and entered to the system at the manufacturing site.	The elements coming out from manufacturers are uniquely identifiable. Any quality issues can be tracked to the specific factory department and time of day.	The construction process is made more complicated. Installation personnel need more devices and training.
Inventory	Storage site personnel need mobile devices.	Elements can be identified automatically and the element status can be exported to logistics management. Manual data entry is avoided. With accurate data logistics need of construction sites can be served better.	The personnel using mobile devices need training for use and mobile devices have costs for purchase and maintenance.
Delivery	Elements need to be read with mobile devices during loading and offloading cargo.	The transportation status of elements is transmitted automatically and any damage occurring during transportation can be recorded and targeted automatically.	The personnel using mobile devices need training for use and mobile devices have costs for purchase and maintenance.
Construction	The construction personnel need mobile devices and the personnel have to tag elements on installation or removal from the site.	Installation status of elements and the need for more elements can be transmitted automatically to logistics management. Quality management data is recorded accurately and transported instantly to management.	The personnel using mobile devices need training for use and mobile devices have costs for purchase and maintenance.
End product: Quality management and inspection (also involved with manufacturing, delivery and performed both during and after construction)	Inspection personnel require mobile data entry devices and RFID readers for identifying the element being examined.	The element that has suffered damage or has a quality issue can be identified uniquely. This allows one to pinpoint the cause of the issue for insurance and process improvement purposes.	The personnel using mobile devices need training for use and mobile devices have costs for purchase and maintenance. Identifying the element with RFID and using the mobile elements can increase the time used for the inspection process.

6. CONCLUSION

In this paper we presented how RFID tracking and mobile technology can be utilized in supply chains for accurate tracking of concrete elements and demonstrated how different services can utilize the tracking data. Combining the increased traceability with an information management system enables improved communication between cooperating partners, reduces duplicated work in information management, and makes it possible to provide more exact, real-time information about the tracked products for quality management and logistics. The logistics chain and the construction site require several changes to facilitate RFID identification and mobile tool based data entry in order to provide increased and more detailed data. The most major changes involve embedding tags to each precast element, registering the elements to the system at manufacture time and integrating readers and mobile devices at each logistics step and the installation process. The benefits of implementing the system through the entire chain include increased and more targeted quality management data, bidirectional flow of information with BIM and current, accurate data about element logistics and supply.

Novel research results from this study show that embedding RFID tracking tags works in precast concrete element lifecycle from manufacture to post-installation. This approach was shown to provide increased durability opposed to the common practice of attaching identification to the cover of the element. Some aspects of the research have been studied in earlier work, like research by Wang (2008) about RFID in construction quality inspection or work made by Irizarry et al. (2013) in displaying supply and building construction status in BIM. Our study extends these studies by using unique RFID identifiers embedded in the elements through the entire process and combining the data from a number of services into a single information management system. Additionally the case extends beyond laboratory tests, with the different services piloted and shown to work in actual construction projects.

There are some limitations to the use of RFID tags in the identification of building materials. The use of embedded RFID identification requires that tag positioning to be considered in the design phase; the tags need to be placed in positions where they can be read in a completed building. This can cause some tags to be unreadable, increasing the number of required tags per element. The use of assistive devices also has to be considered, because the reading of RFID tags requires the use of a medium-sized reader and an integrated reader does not provide enough power to penetrate the concrete. Using several devices increases the complexity of the system, especially when some of them are not small enough to be carried in pockets.

Quality management and quality issues can be a major part of the total costs of a construction project (Barber et al., 2000), an interesting topic for future research would be performing a longer term study that concentrates on the effects on total quality management costs and compares the benefits in quality management to the added costs of RFID tracking. If the number of quality issues or logistics delays can be lessened with the help of information management system services, the reduction on additional costs of construction projects could be major.

7. REFERENCES

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