REALTIME 4D CAD + RFID FOR PROJECT PROGRESS MANAGEMENT

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ABSTRACT
This research presents the integration of 4D CAD with RFID (Radio Frequency IDentification) technology to improve the progress management process. The objective of this research was to build an effective and efficient project progress management framework by integrating 4D CAD with RFID technology under a collaborative environment throughout the supply chain of a construction project. This research proposes a system, named 4D+RFID, that presents building elements in 3D CAD models according to as-built progress, where the as-built information is collected in real-time by sensing the progress throughout the supply chain using RFID. 4D+RFID developed in this research aims at supporting processes with a focus on structural and curtain wall elements, such as steel columns and beams, concrete slabs, and curtain walls, which are typically on the critical path of project schedules in high-rise building construction projects. The process is that RFID is applied to sense the progress status of ordering, delivery, receiving, and erection of building elements, and then the as-built progress information is presented in 3D CAD models. 4D+RFID is under development for use in a high-rise office building construction project in downtown Seoul, Korea.

KEY WORDS
4D CAD, RFID, Ubiquitous Computing, Progress Management, Information System, Supply Chain

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INTRODUCTION

Progress management is one of the critical tasks in construction projects, however it requires a lot of time and effort because of the manual-input-based process used to collect large amounts of information among many parties involved through the life-cycle of a project. Particularly, steel structures and curtain walls in high-rise building construction projects are among the major work items that require more intensive progress management. They occupy a fair portion of the total project cost, and their activities are on the critical path. Since high-rise building construction projects are located in downtown areas, space to stock components and materials is very limited. This condition requires the right materials and components to be manufactured, delivered, and installed at the right time and requires project participants to share and communicate information on progress status as well as on components themselves.

For example, thousands of steel structural elements are manufactured, delivered, and erected in high-rise building construction projects. Through the supply chain process, various information, such as design, manufacturing, delivery, erection sequence and schedules should be shared and communicated among relevant participants including the manufacturer, general and sub contractors. The wrong components can be produced if changes in design are not communicated to the manufacturer in time, and delivery of a wrong or defective component can cause delay in the steel works. Typically, about 3% of contingency cost is included in the total cost of steel works for such waste, however this reimburses only the direct cost of the waste; the impact and loss to the whole project can be much greater.

Therefore it is necessary to have an information system that supports progress management through the supply chain among project participants. Also, progress data in the supply chain needs to be collected and incorporated into the information system in a fast and accurate way so that project participants can manage and collaborate more efficiently and effectively.

As the ubiquitous computing era is emerging, RFID has potential for application in the construction industry, replacing barcodes. A workshop held by the Construction Industry Institute showed that RFID could be feasible and beneficial in many areas including engineering/design, material management, maintenance, and field operations (Jaselskis 2003). RFID, non-contact reading technology, includes tags or transponders that allow sensing of the project’s progress even in harsh conditions where barcodes can not survive. Application of RFID could automate the data collection process not only for construction progress, but also for project progress management throughout the supply chain including design, ordering, delivery, receiving, and installation of material and products. This would make the progress management more proactive and predictable and enable real-time progress management.

In addition, although the advances and applications of 3D CAD have resulted in the concept of 4D CAD (Fischer 2002, Tanyer 2005), which integrates 3D CAD with scheduling to support what-if simulations for construction sequencing and planning, it has not been utilized for project progress management through as-built data collection during the construction phase. However, through the integration with RFID, 4D CAD is expected to be effectively applied for progress management as well as construction planning. Furthermore,
the scope of progress management can then be expanded to cover the whole supply chain of manufacturing, delivery, and installation.

Therefore, the objective of this research is to build an effective and efficient project progress management framework by integrating 4D CAD with RFID technology under a collaborative environment throughout the supply chain of a construction project. This research proposes a system, named 4D+RFID, that renders building elements in 3D CAD models according to as-built progress, where the as-built information is collected in real-time by sensing the progress throughout the supply chain using RFID. 4D+RFID aims at supporting processes with a focus on structural and curtain wall elements, such as steel columns and beams, concrete slabs, and curtain walls, which are typically on the critical paths of project schedules in high-rise building construction projects. The process is this: RFID is applied to sense the progress status of ordering, delivery, receiving, and erection of building elements, and then the as-built progress information is rendered in 3D CAD models.

4D+RFID is under development for use in a high-rise office building construction project in downtown Seoul, Korea. This paper describes and addresses the process model for progress management under the integration of 4D CAD and RFID.

RFID IN THE CONSTRUCTION INDUSTRY

RFID is an electronic labeling and data-collection system to identify and track items using radio frequency (RF) signals. An RFID system consists of four basic components: 1) tag, or transponder, 2) antenna, 3) scanner, and 4) reader. A tag, also called a transponder, is classified as active or passive, and it has read-write or read-only capability (Finkenzeller 2002).

RFID is considered as the next generation technology of bar codes which have been limited in their utilization due to problems, such as ease of damage, low readability under direct sunlight, and lack of durability in harsh construction conditions (Jaselskis 2003). Therefore, taking advantage of the merits of RFID, many research projects have been conducted for its applications in the construction industry; they fall into three categories: 1) identification of potential applications for RFID, 2) verification of applicability and efficiency of RFID application through pilot tests, and 3) strategy and decision-making methodology for RFID applications in the construction industry.

The first category of the research includes a) the identification of potential applications, such as concrete operation from ordering to testing at the job site, cost coding of labor and equipment, and material control (Jaselskis 1995); and b) understanding the feasibility of RFID in the construction industry, based on the applications in other industries (Jaselskis 2000). The second category includes recognition of labor locations using RFID (Navon 2002), field tests for material receipt at power plant and refinery projects (Jaselskis 2003), and field trials for pre-fabricated pipe spools through active RFID (Song 2004). The third category includes Jaselskis’ (2003) proposal for an RFID selection flowchart, which considered various conditions and factors in the construction industry.

As identified by the existing research projects, the current RFID technology has had various barriers to its application in the construction industry, such as lack of standardization, potential interference from metal objects and other radio frequency signals, closed environment for RFID systems, practitioners’ skeptical attitude toward RFID, and high cost.
for hardware (Jaselskis 1995, Jaselskis 2003). However, such problems are increasingly being resolved due to efforts for technological progress and standardization in RFID, plus, the hardware cost, which is the biggest barrier for RFID application, continues to decrease (Lee 2004).

Considering the trend in RFID technology, writers and practitioners involved in this research judged that 1) an RFID application could be more economical compared to a bar code application when reusable RFID tags are used, since RFID tags are reusable indefinitely while bar code tags are not, 2) RFID is much faster than bar codes in tag recognition, and 3) process improvement can be effectively achieved, particularly for the harsh and outdoor-based processes that RFID can be applied to, while it is hardly possible using bar codes due to their technical limitations.

4D+RFID PROCESSES IN HIGH-RISE BUILDING CONSTRUCTION

The 4D+RFID process developed in this research is being developed for the use in Samsung’s SEO-CHO Project, located in downtown, Seoul, Korea. The project consists of three building blocks as shown in Figure 1: 34 floors (160m in height), 33 floors (150m), and 42 floors (200m). Its total floor area is 395,043 m², and each of the buildings is scheduled for completion between the end of 2006 and the middle of 2007. In this project, the general contractor, Samsung Corporation, has decided to apply RFID technology for more effective and efficient project progress in major work items, such as steel structures, curtain walls, and cast-in-place concrete.

![Figure 1: Samsung SEO-CHO Project](image)

APPLICATION STRATEGY FOR RFID APPLICATIONS

This research has been conducted to utilize RFID in the Samsung SEO-CHO project to verify its feasibility in both process improvement and present economic feasibility. Particularly, this research has focused on a method to capture project progress using RFID technology, with minimal cost for hardware, through the supply chain process of components of steel
structures and curtain walls that are typically on the critical path in high-rise building projects and to present project progress by associating it with 3D CAD models.

To minimize the cost of the RFID application, reusable card-type and read-only RFID tags were chosen. A tag is first attached and scanned when the corresponding component is shipped by the manufacturer. It is also scanned in each phase of the supply chain to identify the component, then relevant information is retrieved from the database, and its progress status and other information are changed. To support this, the RFID system was integrated with a Web-based project collaboration system and 3D CAD.

This research did not take advantage of the multi-read capability of RFID, since the installation of antennas and readers for multi-read requires customization to meet the job site conditions, significantly increasing cost. Therefore, it was determined that the individual sensing using PDA-type readers would be the most economical and effective method for this project. Additional details about the RFID applications in this project are described in the following section.

**4D+RFID Process for Structural Steel Elements**

In the supply chain process of steel structures, which includes design, manufacture, delivery, and installation, effective and efficient collaboration among the owner, designer, manufacturer, and constructor is essential. That is, since a steel structure consists of a large number of steel elements, such as beams, girders, and columns, the right elements should be manufactured and delivered to the job site at the right time. To do so, it is important to communicate and share architectural drawings, shop drawings, and numbering information for structural elements in an accurate and consistent manner among project participants throughout the project life-cycle.

The Samsung SEO-CHO project has a total of 5,017 pieces of steel structural elements, and about 40 pieces of elements on average are planned to be delivered daily to the job site. Also, the spiral N construction method was adopted for the erection of steel structural elements, where columns, girders, and beams are constructed zone by zone in a spiral manner so that labors can continue to work without waiting for completion of preceding activities. Therefore, it is necessary to plan and manage the sequence of erections of structural elements.

In addition, since this construction project is located in downtown Seoul, Korea, there is little space to stock structural elements at the job site, and therefore the just-in-time process for delivery and installation was required along with close collaboration between the manufacturer and the general contractor.

Accordingly, the 4D+RFID process for structural elements shown in Figure 2 has been built in the following way. A collaboration system was setup to communicate and share design and component information, such as basic drawings, shop drawings, and component numbers, among project participants. Since delivery and on-site installation require close collaboration between the supplier and the general contractor, manufacturing and construction schedules need to be shared and communicated along with 3D CAD models to show the progress status of components. Once a component is manufactured, a quality inspection is conducted by an employee of the general contractor sent to the factory, and then its progress status changes to “manufactured” and a tag is attached to the component. At this point, an RFID ID is added to the component information, and the corresponding component
information is retrieved and managed by searching for a component that has the same ID number as one of the scanned RFID. Read-only RFID tags on top of magnets were developed to attach to steel elements. They have been successfully tested for readability while attached to the surface of steel structural members.

When a component is shipped from the factory following the construction schedule, it is scanned again using an RFID reader and its status is changed to “shipped.” When the component arrives at the job site, the general contractor determines whether the right component is received and scans the component using the reader, its status changes to “received.” Right before lifting the component by tower crane to the erection position, the tag of the component is detached and scanned, changing the status of the corresponding component to “installed.” Then the tag is returned to the manufacturing factory for reassignment to another component.

Figure 2: 4D+RFID Process for Structural and Curtain Wall Elements

4D+RFID PROCESS FOR CURTAIN WALLS

Curtain walls are becoming more popular in high-rise buildings as an exterior wall system. The curtain wall process is quite similar to that of steel structural elements. The supply chain for curtain walls includes design, manufacture, delivering, and on-site installation; most of its activities are on the critical path of a project schedule, and are managed on a unit basis when unit-type curtain walls are used.

A total of 2,392 units of curtain walls are planned for the Samsung SEO-CHO project, and about 24 units on average are to be delivered daily to the job site. The 4D+RFID process
for curtain walls in this project is the same as the one for steel structural components described above. Design information on a curtain wall, along with unit numbering and information, is shared and communicated through a Web-based collaboration system between the manufacturer and the general contractor. The progress status is also categorized as “manufactured,” “shipped,” “received,” and “installed.” The only difference from steel structures is that curtain walls are not installed using the just-in-time process, instead they are hoisted to and stocked one floor above where they will be installed, and then installed later, unit by unit, using a winch. Therefore, when the status of a curtain wall unit is “received,” its stock location needs to be recorded.

4D+RFID PROCESS FOR CAST-IN-PLACE CONCRETE

In the Samsung SEO-CHO Project, although its main structure is made of steel, a great amount of cast-in-place (CIP) concrete is used for mat foundations and slabs. In this project, the total amount of concrete needed in this project is 19,575 m$^3$, and the daily average for concrete is about 200 m$^3$, which requires about 33 concrete trucks on average and about 50 trucks at maximum.

The 4D+RFID process for concrete operation has been performed through the collaboration between the concrete supplier and the general contractor as shown in Figure 3 and Figure 4. The construction manager inputs plans for CIP concrete operations, and the order manager issues purchase orders through the Web-based collaboration system when necessary. At that moment, the order manager not only gives the quantity and material specifications but also gives instructions on desired time when the material should arrive at the job site and the gate number where trucks should come so as not to cause a traffic jam at

![Diagram of 4D+RFID Process for Cast-In-Place Concrete](image-url)

Figure 3: 4D+RFID Process for Cast-In-Place Concrete
a particular gate. When the order is completed, the status of the corresponding component in the 3D model is changed to “ordered.” Following that, the concrete supplier confirms the order and produces concrete. When concrete is loaded into a truck, the supplier issues an invoice along with a RFID card, and adds information on departure time, truck registration number, quantity, and material specification to the Web server. When the truck comes to the designated gate, the RFID reader installed at the gate reads the RFID card, the server searches for the invoice number associated with the same ID, and then the status is changed to “received.” The Web server accumulates the quantity of the corresponding components and changes the status to “installed” when the accumulated quantity reaches the total quantity of components. When the truck leaves from the job site, the reader reads the RFID card again, the supplier then knows which truck is coming back.

Figure 4: Supply Chain Management for Concrete Work Using RFID

4D RFID SYSTEM

The 4D+RFID system has been developed to support the process for steel structural elements, curtain walls, and cast-in-place concrete as described above, and the system architecture is shown in Figure 5. To support the collaboration among project participants, DoallTech ’s Project™ Center, a Web-based collaboration system, was adopted. The Project™ Center was customized to support not only project management functions, but also the 4D+RFID process by associating it with RFID readers and 3D CAD.
125 kHz RFID technology was adopted in this project, since 900MHz is not allowed in Korea yet (it is supposed to open to the private sector by 2005). Although 13.56 MHz technology is also available in Korea, the tuning of its antenna is relatively difficult and expensive, while the tuning for 125 kHz is easier and cheaper. Even though 125 kHz technology has a problem such that a reader can interfere with another reader when they are close to each other (within 1 m), it was chosen for the SEO-CHO project since that situation would not occur in this project and its hardware cost is much lower than any other RFID technology available at this time in Korea.

Figure 5: System Architecture

Project progress information sensed by RFID readers is reflected on the corresponding 3D models in ArchiCAD 9.0™. The system searches the component that has the same RFID tag ID and changes its color to indicate its progress status. Project scheduling is managed using SureTrak™, and activity information is associated with 3D models in ArchiCAD™ through ODBC (Open DataBase Connectivity), which enables simulation for as-built progress as well as for the as-planned schedule.

CONCLUSIONS
This research proposed a method to integrate and utilize 4D CAD and RFID through the supply chains of steel structures, curtain walls, and CIP concrete. The progress of the corresponding components were identified and presented in 3D CAD models using RFID technology to sense the project progress. Also project participants in design, manufacturing, and construction collaborated and shared information through the supply chain. In addition, process models were developed to show how the 4D+RFID concept can be realized in each process for steel structures, curtain walls, and CIP concrete.
The 4D+RFID system is still under development and at the early stage of implementation in the Samsung SEO-CHO project at this time. However, this paper shows the feasibility and potential for RFID application such as tracking project progress along with integration with 4D CAD in construction projects. Authors believe that contributions for improvement, problems and issues of this research can be shared in more detail during conference presentation, and hopefully through future publications.

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