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Abstract

Progress management is demanding because of the volume of information exchanged among the various parties involved in a project. In particular, steel structures for high-rise construction projects are among the major work items that require more intensive progress management. This research aims at developing a real-time progress management system through an automated module for scheduling estimates and using an RFID system for real-time construction progress. We propose a new technique that preconstruction engineers can use to build a schedule estimation using 3D-CAD and a Database. By using these tools, engineers can visualize then analyze real-time, actual construction progress with on-site RFID and robot systems. The real-time progress management system developed in this study maintains the continuity of the information from 3D design, the accuracy of lists of materials, the automation of expected progress, and the management of actual progress.

Keywords: steel structural construction; progress management; database; RFID; visualization; 3D-CAD

1. Introduction

1.1 Background and Goals of the Research

Computing tools greatly enhance collaborative decision-making and performance among participants in a construction project. However, the current use of computing tools does not capitalize on the available benefits (Kunz *et al.*, 2001). The benefits of graphical construction simulation via 4D modeling have been demonstrated in previous research and include the identification of work sequence conflicts, potential safety hazards, and improved communications of the plan to the crews (McKinney and Fisher, 1998). Progress management is a critical task, requiring much time and effort because of the manual-input-based process used to collect large amounts of information among the many parties involved during the life cycle of a major project. In particular, steel structures and curtain walls in high-rise building projects are among the major work items that require more intensive progress management (Chin, 2005). Because progress management has previously been performed mainly through manual and paper-based processes, it has been difficult to share as-built information of steel components and even more difficult to monitor the supply chain of steel components (Chin, 2008).

Here, we aim to develop a real-time progress management system through an automated module for scheduling estimation and an RFID system for real-time construction progress. We propose a new system that preconstruction engineers can apply to build automatic schedule estimation using 3D-CAD and Database and visualize then analyze the real-time actual construction progress using on-site RFID and robot systems. Through this system, a practical approach can be applied by the project team (owner, contractors, managers, etc.) to facilitate the scheduling process at the preconstruction stage and analyze the real-time progress of the construction.

1.2 Scope and Contents of the Study

In this paper, we propose a system for real-time construction progress management of the steel structural phase. High-rise buildings are our target, and we apply 3 sections for our 3D model sample. One is the highest section and the others are typical sections that include many repetitive activities.

This study researches the construction automation of the high-rise structures on the basis of the robotic crane technology and the assembly and installation of the steel frame structure. The study has been divided into

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three sections. The first section describes a module for generating an expected progress schedule; the second section elaborated on the module that can be used for automatically extracting the movement and installation of materials; and the third section discusses the module that can be used to analyze and check the expected progress schedule and actual progress information.

2. Literature Review

The development of a real-time progress management system for steel framework based on a robotic crane differs from the conventional 4D system or process simulation system. Similar research content is rare. For this reason, in this study, we conducted a literature review of 4D simulation systems and process management systems related to basic technologies such as shape presentation.

A resource-constrained, multi-project scheduling problem is defined as scheduling two or more projects simultaneously with the objective of minimizing the total project delays. Previous research on this kind of scheduling problem has been directed primarily toward developing efficient scheduling rules that minimize total project delays (Pritsker, 1969).

A 4D visualization model is the end result of linking components of a 3D CAD model to the assigned construction schedule software. 4D visualizations are much easier to understand than conventional tools such as CPM or bar charts, which have previously been used to manage construction projects. During the past decade, extensive research has been conducted on the concept of a 4D model, which incorporates the time dimension into 3D visualization. McKinney *et al.* (1998) delineated a construction example to illustrate how feature extraction in 4D CAD models can help identify construction problems, and they evaluated the quality of the construction plan through 4D analysis and annotations. Koo and Fischer (2000) concluded that 4D models are a useful alternative to project scheduling tools such as CPM networks and bar charts.

Visualization theory stresses several principles when creating data graphics, including structuring and filtering, editing for density, and communicating efficiently. The visual framework shown in Fig.4. illustrates the iterative process of implementing each of these principles when creating data graphics for project control data (Anthony, D., 2003). The main system reads and normalizes a set of cuboids, which can be translated from 3D CAD data, then interprets a construction method template to decompose the cuboids, adds some attributes, and finally produces a quantity takeoff, a schedule, and a visualization of the processes over time (Kataoka, 2006). The movement covers all directions on the basis of a working area, and a worker who occupies each area changes according to a time series. For these reasons, it is necessary to examine the tasks, movements, and time comprehensively to collect the location information (Chae, 2005).

Chin (2008) built logistics and progress management processes for structural steel works within the integrated environment of RFID and 4D CAD technologies, based on the application strategy described above, and named it the RFID+4D CAD process.

3. Current Problems and Rectifications

3.1 As-Is Model and Current Problems Analysis

In this section, we analyze the As-Is model of a phased construction process carried out for current steel framework, including problems classified by phase (Fig.1.).

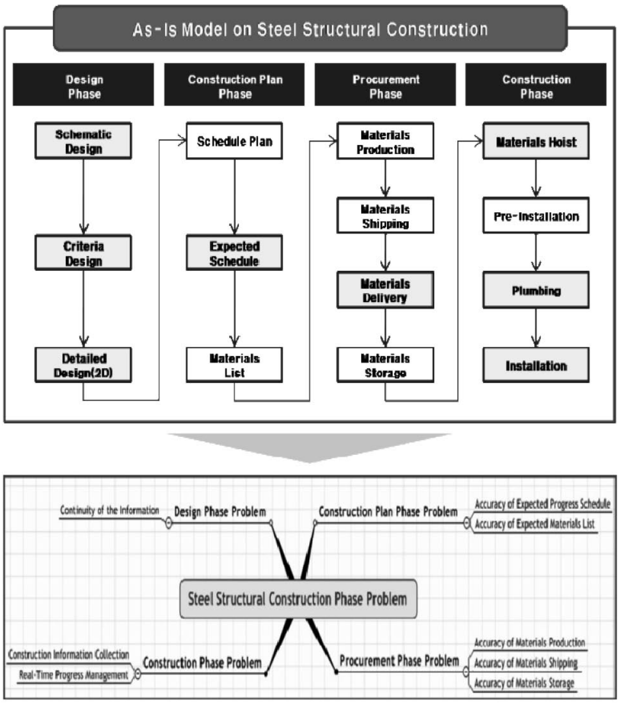

Fig.1. As-Is Model and Current Problems

In the design phase, a schematic design, a criteria design, and a detailed design are carried out using a 2D design. However, 2D design has some disadvantages. Maintaining the consecutiveness of information after the design phase is difficult. In addition, when a design error is found, changing the design can become time-consuming work.

In the construction-planning phase, professionals who schedule progress invest a lot of time in writing a schedule table based on drawings designed by 2D, and then estimates professionals make a list of the quantity of materials. In this process, too much time is spent and human errors can be numerous. Materials procurement is based on a schedule table made in a previous phase, but it is not easy to manage information precisely at every stage, including information about shipping, delivery, and storage.

In addition, communication problems can occur between site managers and material producers, and information sharing can be difficult. For these reasons, work is delayed and costs rise. In the early construction phases, such steps as hoisting, temporary bolting, plumbing, and main assembly are under way, and real-time status is difficult for the site manager to monitor. Additionally, some difficulties arise when comparing the schedule table and actual on-site situation.

3.2 To-Be Model and RTPM System Concept

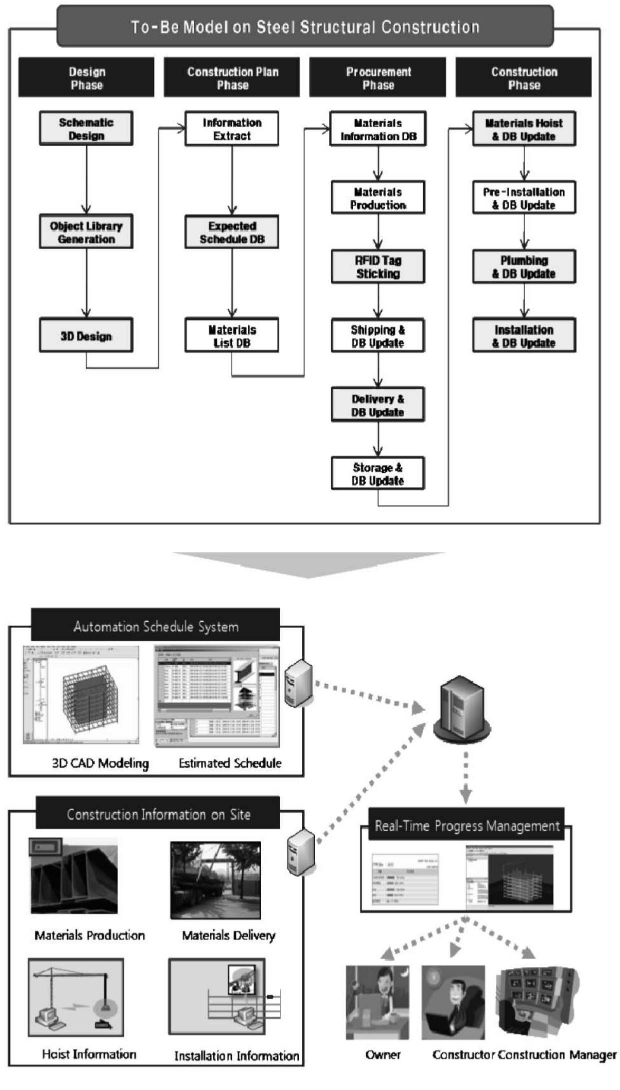

Fig.2. To-Be Model & RTPM Concept

To remove similar problems from the analytical results of an As-Is Model, we designed a To-Be Model that introduces a Real-Time Progress Management (RTPM) System that allows more efficient control.

Once the basic concept is established through a schematic design (Fig.2. Top), an object library is generated and a 3D design is created. This process reduces the design errors of 2D drawings and improves the drawing information.

The system extracts object information from the 3D design and saves it in Database, and then schedules the construction progress automatically by module. The construction progress schedule and the extracted materials list based on actual data are more precise than those generated by professionals.

Producers in a factory can check information about the materials list via an Internet server. They can also get precise information about movements and installments of materials by applying real-time RFID and thus prevent delivery delays. After materials are stored, construction work can begin according to the on-site process. Without a site manager, we can manage real-time progress information by comparing it with the current schedule. Additionally, in this study, the site progress status is more easily understood by the application of real-time visualization.

The RTPM system extracts the 3D CAD object information and stores it in the integration Database, automatically gets basic and hoisting information from the system, and generates expected progress information and then stores that information in the Database (Fig.2. Bottom). Once the work begins, real-time progress information is available from the RFID system, intelligent hoisting system, and robot system, then actual work progress information is stored in the Database and compared with expected progress information previously saved. The progress management status can be analyzed showing the real-time status visually.

In order to establish the RTPM system, we conducted this study on three sections:

1) Automatically expected progress schedule module: Generates information by extracting the times for main bolting, hoisting, temporary bolting, and plumbing of steel framework, based on information from robot bolting, tower cranes, and 3D CAD.
2) Material life cycle extraction module: Collects information about material status and life cycles (production, delivery, hoist, and installation).
3) Real-time progress management system: Analyzes real-time progress status and productivity based on information about expected and actual progress. Moreover, a manager can check the status visually by actually being on site.

4. RTPM System Design

4.1 Process Model for RTPM System Design

In this study, we designed a real-time progress management system to efficiently monitor steel framework based on the To-Be Model. The IDEF0 modeling method is specially designed to model activity based on behavior, decision-making of an organization or system, and function. This method analyzes organizations and systems and communicates with them in terms of function, based on the cell modeling graphic expression method. As an analytical tool, IDEF0 defines the respective functions and resources required to perform a task. An IDEF0 model diagram is shown below in Fig.3.

"Activity" indicates functional action, motion, process. "Input" indicates input information by arrow into the left of Activity Box. "Output" indicates information fabricated by Activity, which is represented by the arrow from the right side of Activity Box.

"Control" is the arrow, which comes down from the upside, control-performing Activity. "Mechanism" is the arrow, which comes up from the downside of Activity Box, which indicates the subject of Activity. (Fig.3.)

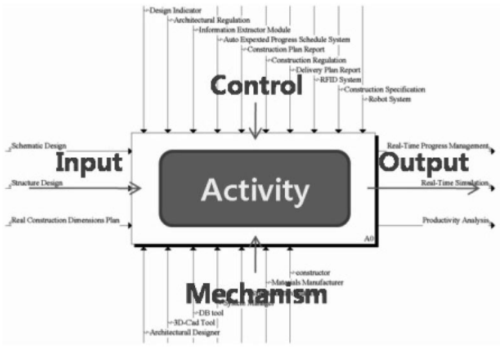

Fig.3. IDEF0 Model

In the modeling phase (A1), a schematic design, structural design, and real construction information are input, and information about the location of materials database (DB) and about the specific materials DB is output according to control factors.

In the construction-planning phase (A2), output factors (materials location information DB and materials character information DB) produced in the previous phase become input factors. Tower crane information DB, materials information DB, and expected progress schedule DB are obtained by control and mechanism factors.

In the procurement phase (A3), output factors (tower crane information DB, materials information DB, and expected progress schedule DB) produced in the previous phase become input factors and materials status DB and materials storage on site information are obtained by control factors.

In the construction phase (A4), output factors (materials status DB and on-site materials storage) become input factors: real-time progress management and simulation. Productivity analysis is obtained by control factors (Fig.4.).

4.2 DB Model for RTPM System Design

In this study, we designed a data modeling method to establish an integration DB by using the Entity Relation Diagram (ER-Diagram, which has shape-combining network and relation models.

Using this method, we obtained the information required. Fig.5. shows the integrated DB structure of the real-time progress management system designed by ER-Diagram.

- tblProject: Table to manage the basic information of the construction project
- tblBasicCode: Table to manage necessary information (start and finish times, number of working days, etc.)
- tblTowerCrane: Tower crane library used for

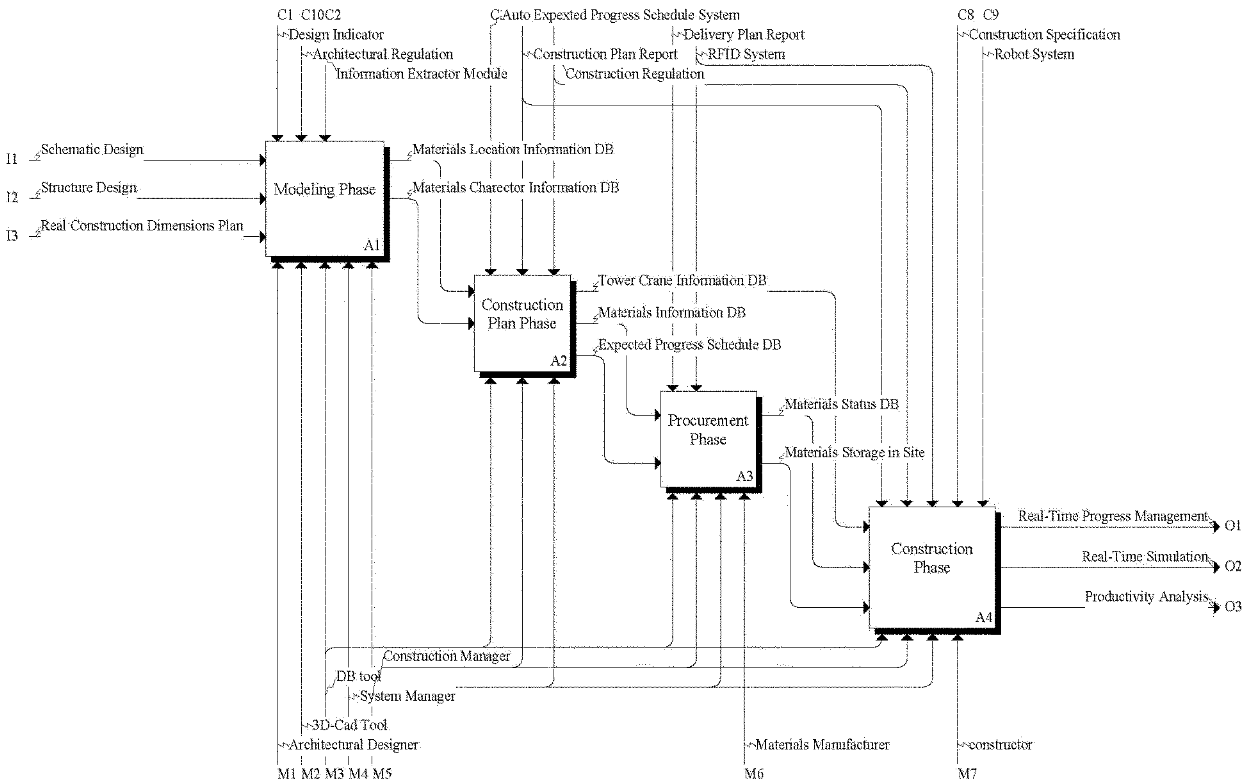

Fig.4. IDEF0 Model (Process in A0)

construction work

- tblProjTCrane: Table to manage information about height, ID, and location of tower cranes for a specific project
- tblMaterial: Table about library information management, which is managed in connection with library of object CAD.
- tblObjects: Table to manage unit-classified information of the design object. Position information is managed with the time to take in the construction site.
- tblGrids: Method to manage and extract information about grid and object coordinates
- tblRobot: Table to manage information about construction robot
- tblRob_Obj: Table to manage information about robots at work on the design object
- tblSchedule: Table to manage the schedule for the construction project
- tblSch_Obj: Table to connect process and design object information
- tblLevels:Table Table to save and manage information for the building design
- tblHorZone: Each lifting time differs according to the position of the install member, so it is necessary to manage the lifting time separately according to the height
- tblHZone_Level: Table to manage connection between vertical zone and level, which have a lifting time gap

5. RTPM System Realization and Application

5.1 3D Modeling for Application

The object library for steel materials was made using a 3D CAD tool. The connections between columns and beams or beams and beams have been made in accord to the X, Y grid, and Z level. In this way, we can easily extract the location information of each object. A 3D model was designed for seven stories (Fig.6.).

5.2 Automatic Expected Progress Schedule System Module

This module works according to the following steps. In the 3D Design Object Extraction Phase, we installed a material information extractor module in a 3D CAD tool, and then extracted location information (Fig.7.).

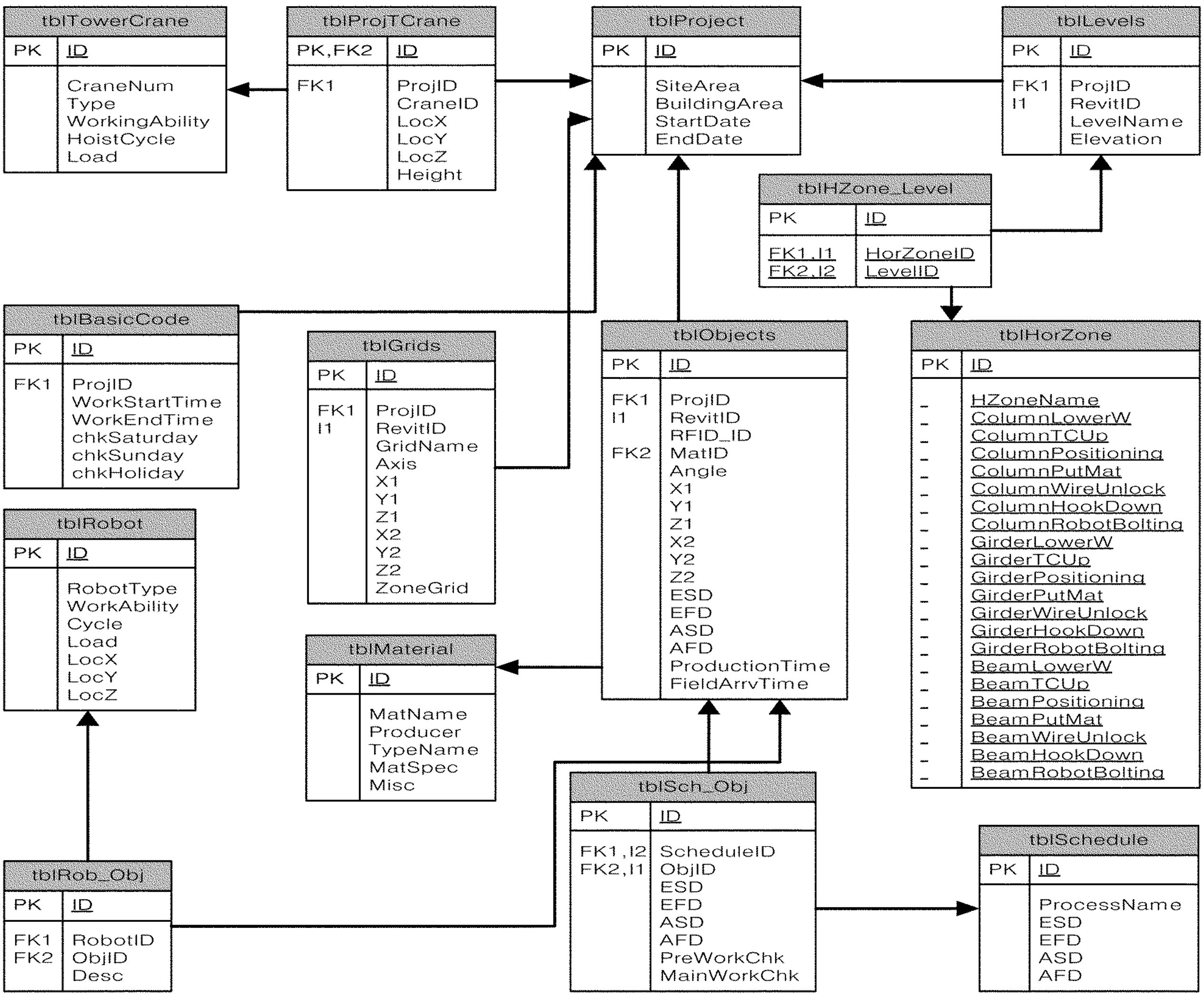

Fig.5. Entity Relation Diagram (Structure of RTPM System)

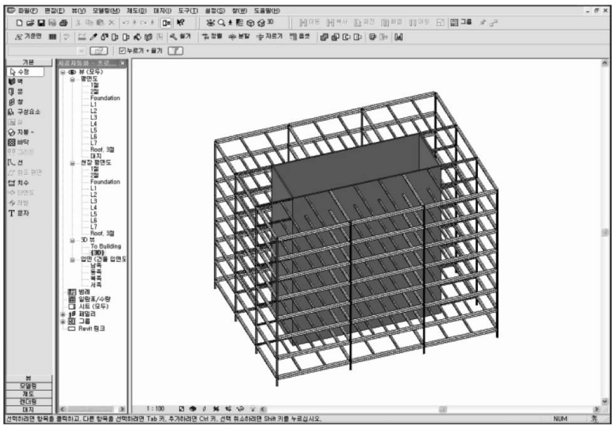

Fig.6. 3D Modeling for Application

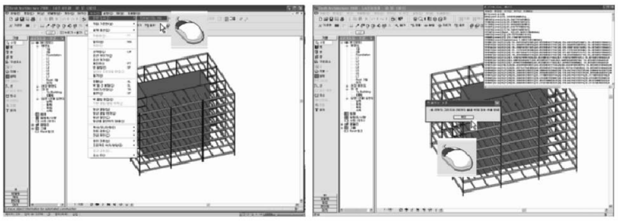

Fig.7. 3D Design Object Extraction

To establish each working zone, we separated each work area. In the horizontal view, if the tow tower crane is set on the construction site, each work area of these two tower cranes must be separated. Modeling objects for this study were very small, so we planned to install only one tower crane.

In the vertical view, within a typical section, the working speed of each section is similar. However, in the case of an over- typical section, there are some differences in working speed; hence, they should be appropriately divided. In addition, discrimination in the vertical phase is necessary. For this modeling, typical sections are grouped into Middle-section, over- typical sections are grouped into High-rise. (Fig.8.)

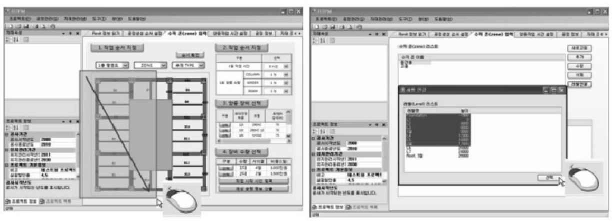

Fig.8. 3D Design Object Extraction

In the Hoist Plan Establishment Phase, we set up a hoist plan within each working zone. To generate an expected progress schedule for each material, we input information about hoisting. We also set a beginning time of hoist work for the steel framework, a holiday or not, and the work rates of tower crane (hanging members on the hook, lifting wire, dropping wire, revolving wire, T/C lifting). We also set up the work rates of robots (movement, temporary bolting, erection checking and revision, main bolting). Utilizing actual job data would be more accurate, but we used general data from interviews for this study (Fig.9.).

Fig.9. Hoist Plan Establishment

For the steel framework, the order of hoisting materials is altered according to daily conditions and circumstances. In this study, we set the order and the beginning point of section units and materials. We then set virtual situations that reflected the on-site conditions (Fig.10.).

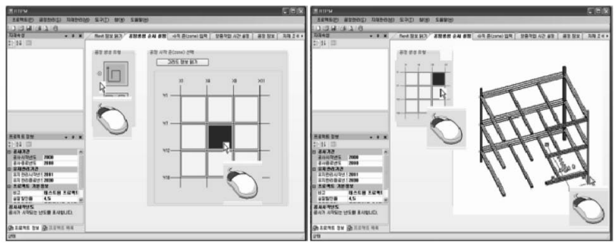

Fig.10. Working Start Point and Order Establishment

Through previous processes, we generated a progress schedule on the basis of data obtained before actual construction.

The expected progress schedule DB consists of information about schedules, hoisting, preliminary installation, and plumbing and installation classified by section and materials. In Materials DB, information about column, girder, beam materials lists, production period, delivery, loading, and material prices is shown in Fig.11.

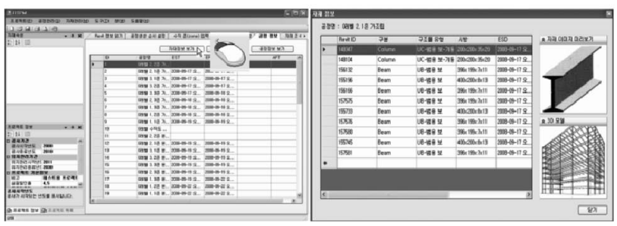

Fig.11. Expected Progress Schedule and Materials DB

5.3 Materials Life Cycle Extraction Module

For transporting and delivering materials at the construction site, we collected real-time information (Fig.12.).

Materials Procurement Cycle: material production and RFID Tag attachment; recognition and transmission of materials by RFID at the time materials are taken out of plant; recognition and transmission of materials by RFID at the time materials are being taken

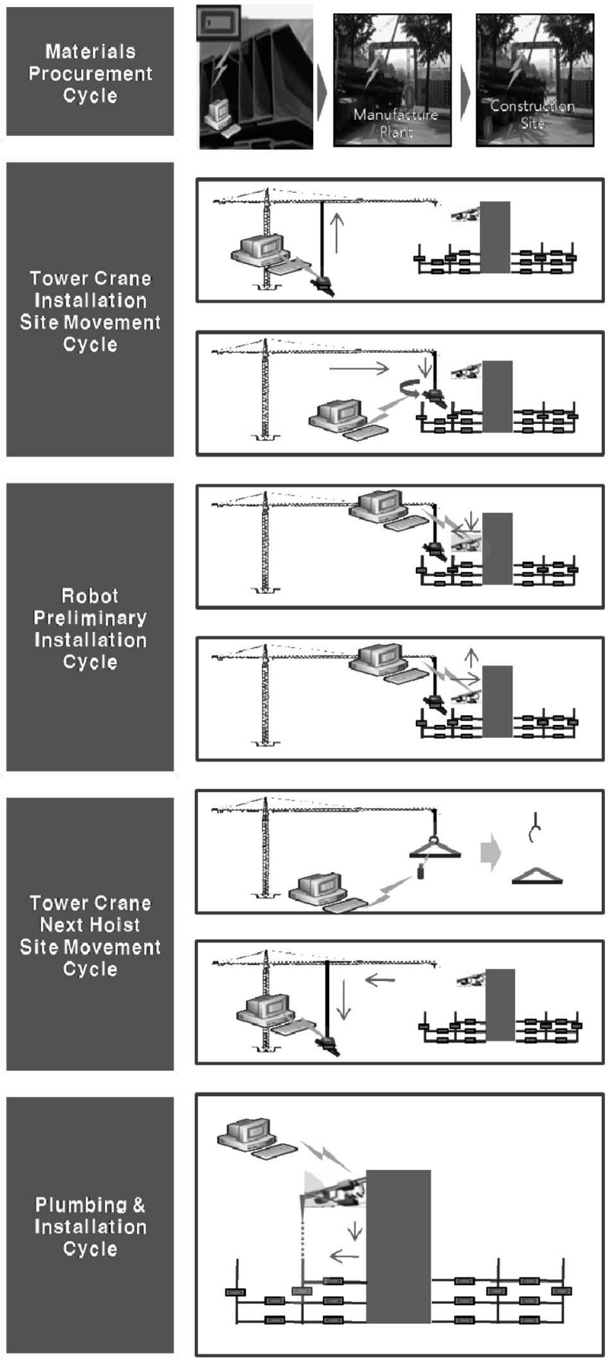

Fig.12. Materials Life-Cycle Extraction Module

to a site.

Tower Crane Installation Site Movement Cycle: Hanging materials on a tower crane hook; recognition and transmission of materials by RFID; transmission of material installment position; carrying to intended position; revision of material position; transmission of termination information.

Robot Preliminary Installation Cycle: Movement of robot to material position; recognition and transmission of materials by RFID; checking the bolting position; robot movement to bolting position; temporary bolting by robot; transmission of termination information at the time when temporary bolting is completed; movement of robot.

Tower Crane Next Hoist Site Movement Cycle: Acquisition of temporary bolting termination information by tower crane; hook dismantling by tower crane; transmission of dismantling termination information; move to next hoisting place; recognition and transmission of next material by RFID.

Plumbing and Installation Cycle: Checking the erection degree by laser system; transmission of erection checking start information; revision of erection by robots; main bolting by robot; information transmission after termination.

5.4 Pilot Test of RTPM System

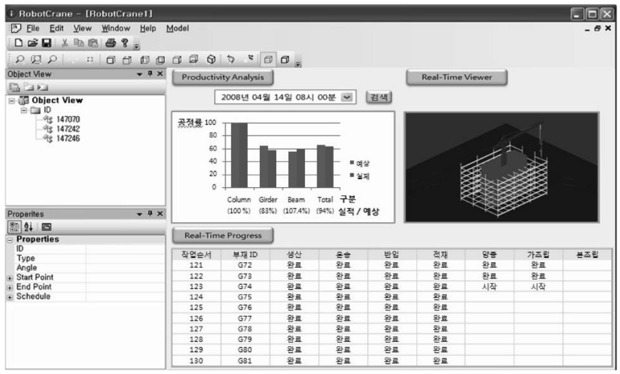

Fig.13. Real-Time Progress Management

Fig.14. Productivity Analysis

The process rate views in Fig.13. show both the expected process rate and the actual process rate, including the performance rate to the expected rate. Real-time views show the real-time progress status of the current process. Real-time progress shows the current progress of each member.

The view in Fig.14. is composed of robot and tower crane and is divided into columns, girders, and beams. In robot parts, data analyses are carried out in cycle time needed to assemble each member temporarily, and the other cycle time needed for plumbing and main assembly. In tower crane part, data analyses are carried out in cycle time needed to move installation into place, and the other time needed to move the next

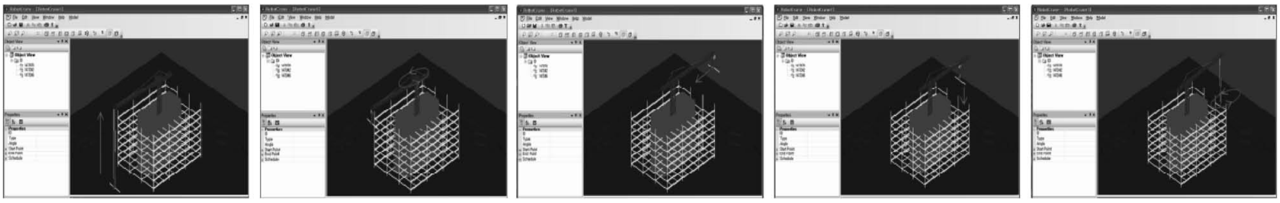

Fig.15. Progress Management Simulation

members.

Progress management simulation in Fig.15. is for the time. The work progress status can be easily understood according to time flow.

6. Conclusion

In this study, we extracted object information and expected automatic process information through 3D modeling, and composed a system to manage information about work processes on the basis of a site management system.

The main conclusions of this study are as follows:

1) With object information extracted from 3D CAD, we can secure relativity with subsequent matters and the consecutiveness of design.

2) It is possible to get precise processes and material quantities by using a module to produce expected process information if information data about tower cranes and robot installation are well established.

3) We can check the material production, shipping, onsite warehousing, and load status in real-time and prevent work delays in advance.

4) We can get precise on-site data and make real-time work management more efficient through an RFID system.

5) We can monitor the situation in real-time, analyze the productivity, and simulate in advance the work progress status according to time flow. Therefore, we can efficiently manage work progress.

In the next study related to the steel frame process management system developed through this study, it is necessary to compensate for the shortcomings of the current model in order to development a more intelligent model. We expect to raise the practical application possibilities and the project information management levels.

Acknowledgments

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