USING BIM MODEL AND GENETIC ALGORITHMS TO OPTIMIZE THE CREW ASSIGNMENT FOR CONSTRUCTION PROJECT PLANNING

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ABSTRACT

Project planning is among the most critical factors to the success of a construction project. In project planning, cost and schedule are closely interrelated, because they share a lot of common data in their planning processes. Therefore, the integration of cost and schedule functions has been an attractive issue in construction project planning. Many researchers have emphasized the benefits of this integration and several different methodologies combining cost and schedule data have been provided. However, the results of the previous studies are not comprehensive enough to fulfill the requirements of project planning. This paper presents a model-based planning system that employs Building Information Model (BIM), Object Sequencing Matrix (OSM), and Genetic Algorithms (GAs) to obtain an optimal crew assignment under resource and workspace constraints. The purposes are to evaluate the project costs and optimize the temporal distribution of resources in project planning. A computer implementation called Cost/Schedule Integrated Planning System (CSIPS) is also developed to verify the feasibility of the proposed approach.

Keywords: BIM model; Crew assignment; Genetic Algorithms; Project planning

1. INTRODUCTION

Project planning is among the most critical factors to the success of a construction project. In project planning, cost and schedule are closely interrelated, because they share a lot of common data in their planning processes. Therefore, the integration of cost and schedule functions has been an attractive issue in construction project planning. Many researchers have emphasized the benefits of this integration and several different methodologies combining cost and schedule data have been provided (Jung & Woo, 2004; Chen, 2008). However, the overhead efforts of collecting and maintaining detailed data have been highlighted by previous research as the major barrier to utilizing this concept in real-world implementation (Lee & Yi, 1999). Advance information technology has been recognized as a definite solution in the integration of project cost and schedule (Kang & Paulson, 1998). Besides utilizing information technology, optimizing planning methods can be another solution that can result in reducing the amount of required efforts.

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This paper presents a model-based planning system that employs building information model (BIM) (NBIMS, 2008), object sequencing matrix (OSM), and genetic algorithms (GAs) to generate a cost-schedule integrated plan for construction management. The proposed BIM model incorporates multi-aspects of construction information required for project planning and management. In order to present the information of construction activities and specifications in the model, this research starts with analyzing the discrete processes within the building construction. The essential characteristics of building components are then defined in the property sets of the BIM CAD objects (Feng & Chen, 2008). These graphic objects are then further developed as schedulable objects and utilized to create the BIM model.

To schedule the construction project, BIM model and the object sequencing matrix (OSM) are adopted to determine the construction sequence of building components based on the physical relationships between BIM CAD objects. Since a building generally consisted of thousands of building components, this research applies GAs to optimize the construction sequence because of its capability of handling the large-scale optimization problem. This optimized sequence servers as a basis for project scheduling. In addition, the GA-based crew assignment includes the evaluation and optimization of the temporal distribution of resources and costs is applied in the project scheduling. Since the resulting schedule is integrated with project cost, it becomes possible for project planners to easily examine relevant resources and costs of a specified time period. The meaningful information generated from the cost-schedule integrated plan will be useful for management to execute the project requirements.

This article is organized in the following manner. First, the procedures for developing a BIM model are discussed in further detail. Next, the proposed project planning method is described. Finally, a computer implementation called Cost/Schedule Integrated Planning System (CSIPS) is presented to verify the feasibility of the proposed approach.

2. BUILDING INFORMATION MODELING

The proposed model is an extension of a BIM model, which consists of BIM CAD objects and incorporates multiple types of construction information required for construction planning and management. In order to present the information on construction activities and specifications in the BIM model, this paper analyzes the discrete processes undertaken within facility construction. Several facets, such as dimensions (e.g., width, area), spaces (e.g., office, classroom), elements (e.g., column, beam), materials (e.g., steel bars, concrete), work sections (e.g., cast-in-place concrete, painting), management (e.g., regulations, cost) are used to classify the construction information. The standard classifications organize the attributes' structure of a BIM object. These attributes are divided in three aspects include geometric data, containment hierarchy, and construction contents, and are used to present the essential properties of building components as depicted in Figure 1.

In the geometric aspect, the attributes include the coordinates and dimensions of the building component, and the physical relationships with the adjacent components. In the containment hierarchy, the BIM model is structured per the IFC BIM standard (NBIMS, 2008; IFC Model, 2008). The building components are further classified into physical, spatial, and logical CAD objects in this paper. This containment hierarchy defines the structure of the BIM model and is useful for integrating and processing project information. In construction contents, the work necessary to construct the building components is described by the specifications of the required work sections. Typically, each design component in the planned facility will have one or more associated work items. The work items employed in this study are classified and coded according to the hierarchical standard codes established by the Public Construction Commission (PCC) in Taiwan (PCC, 2009).

The PCC coding system was developed with reference to the CSI MasterFormat system (MasterFormat, 1996). As a result, the information of construction contents is organized into the project-required work presented graphically by the BIM objects. The BIM objects are utilized to create a BIM model in an IFC-based CAD system. After the creation of the BIM model, all project-required work can be identified based on the collected work items in the BIM objects. The large amount of information described in the BIM objects will be exported as a relational database for project planning. The use of standard classifications enhances the integration of construction information and also improves the viability of integrated cost and schedule planning systems by reducing the overhead efforts and by reusing historical databases.
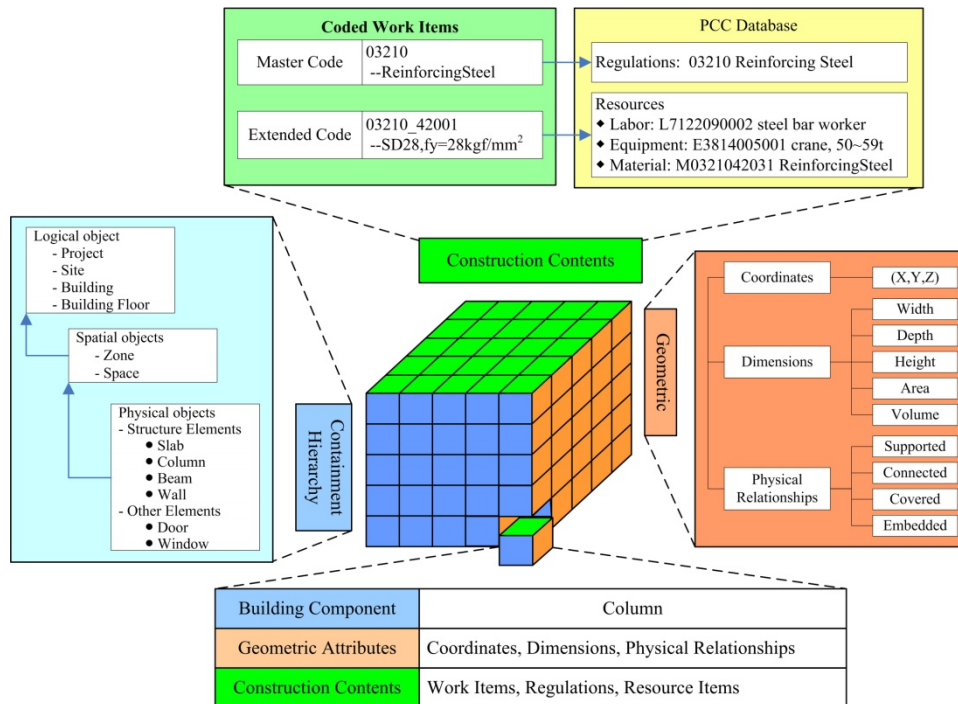

Figure 1 Structure of the attributes of a PIM object

3. GA-BASED SCHEDULING

3.1. Object sequencing matrix

In the proposed scheduling method, the physical relationship between building components, which is defined by the geometric attributes retrieved from the BIM objects, is utilized to formulate the construction sequence of the components and is presented in the Object Sequencing Matrix (OSM). As shown in Figure 2(b), the circled "S-D" indicates that object C1 (column) is "supported directly by" object B1 (beam), the circled "S-I" indicates that object W1 (wall) is "supported indirectly by" object B3 (beam), and the circled "D" indicates that object W3 (wall) "depends on" object C1 (column).

The sequence of objects in OSM is the construction order of building components. As shown in Figure 2(b), the circled "S-I" in the upper-right zone indicates that object C1 is supported indirectly by object B4, i.e. object B4 must be installed before object C1. Therefore, object B4 should be scheduled before object C1. In other words, the object relationships in the upper-right zone of the matrix should be all moved to the lower-left zone, which is the rational sequence of the building components. Based on these precedence relationships between building components and regardless of the construction continuity, a number of possible construction sequences will be developed. In order to generate a more practical construction sequence for

building components, the relationships in OSM conformed to the continuity condition will obtain a higher weight value in the sequencing algorithm (Figure 2(c)).
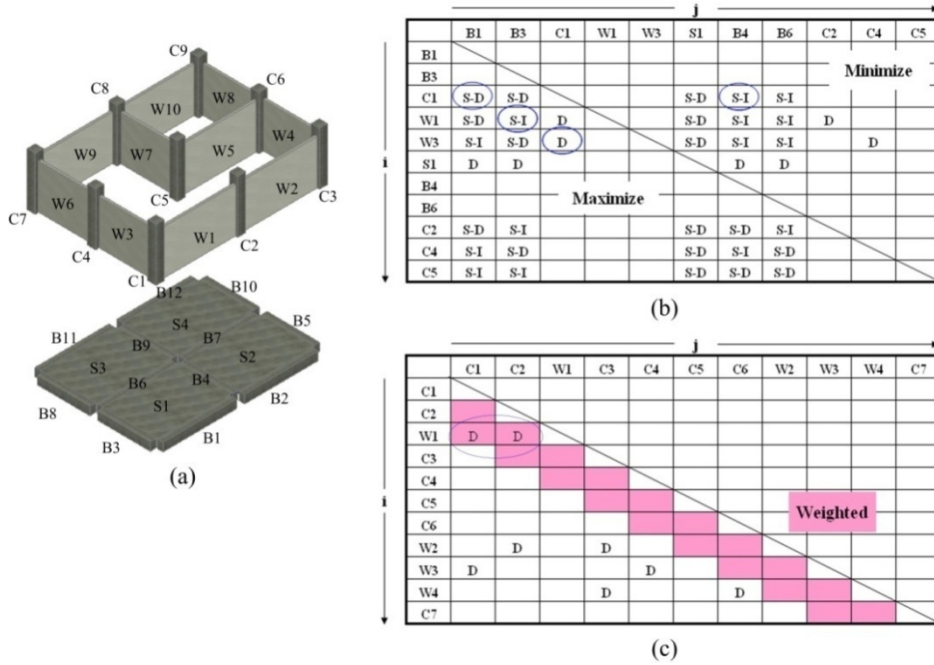

Figure 2 Object sequencing matrix (OSM): (a) building components; (b) relationships between building components; (c) relationships conformed to continuity condition

The chromosome structure

In this study, a possible sequence of building components is presented in a chromosome string. The chromosome string is encoding in real number. As shown in Figure 3, the genetic codes represent the positions of the building components in the sequence. Building components are then listed in OSM matrix according to the genetic codes (Figure 2(b)).
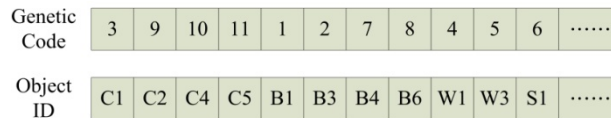

Figure 3 The chromosome structure of component sequence

The fitness value

The relationships between building components are coded in the OSM. In this research, the value of relationships with inflexible constraint is set as 1; otherwise the value is set as 0. In addition, the weighted value of relationships that conform to the continuity condition is set as 2. As mentioned above, to obtain a rational construction sequence of building components, the relationships appear in the upper-right zone of the matrix should be moved to the lower-left zone, i.e. the sum of values in the upper-right zone should be minimized (the appropriate value = 0). Hence, the fitness function is given as Equation (1):

$$Min.\ f(m) = \left(\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} OSM(i,j) \right)$$ (1)

where m is the size of initial population, n is the number of objects. When all the relationships are moved to the lower-left zone of the matrix, the sum of the weighted values should be maximized. The fitness function is given as Equation (2):

$$Max.\ g(m) = 2 \times \left(\begin{array}{c} \sum_{j=1}^{n-D} \sum_{i=j+1}^{j+D} OSM(i,j) + \\ \sum_{j=n-(D-1)}^{n-1} \sum_{i=j+1}^{n} OSM(i,j) \end{array} \right) + \left(\sum_{j=1}^{n-(D+1)} \sum_{i=j+(D+1)}^{n} OSM(i,j) \right)$$ (2)

where n is the number of objects, D is the given continuity condition.

Evolutionary Mechanism

The evolutionary mechanism follows the procedures of initialization, selection, crossover, mutation, etc. At first, the initial population of possible sequences is randomly generated. Two main selection mechanisms, namely elitist selection and roulette wheel selection are then applied to find the better strings. Then, the uniform crossover (Gen & Cheng, 1999) is applied for chromosomes' crossover. After this procedure, several genes in the chromosome will undergo the process of mutation in order to ensure that the solution is in global optimum instead of local optimum.

After GAs' evolution and convergence procedure, the obtained optimal sequence of building components has considered both the physical relation between objects and the continuity of construction. Combining with the logical constraints of the process of work, such as the sequence of place steel reinforcement, place formwork, and place concrete, a logic network of the building component-based activities could be established and served as a basis in crew assignment.

3.2. Optimal crew assignment

In order to integrate the project cost with project schedule, this study applies GAs to obtain an optimal crew assignment under resource and workspace constraints. The purposes are to evaluate the project costs and to optimize the temporal distribution of resources in project scheduling. For now, this study focuses on the crew assignment of cast-in-place concrete engineering. A larger amount of building components with the detailed construction activities include the Structure Steelworks, Structure Formworks, and Concrete Pour Works are demonstrated

Chromosome Structure

The daily crew assignments to each activity are presented in a chromosome string. As shown in Figure 4, in a workspace that allows a maximum of 10 crews, the genetic code (1) 8 2 0 means that the assignment of crews to Steel Works, Form Works, and Concrete Works on the first day is 8 crews, 2 crews, and none respectively. The initial crew assignment are randomly generated and the strings are input into Str(m,n), while m is the size of initial population (1~Pop_Size), and n is the length of the string (n=1~N×4, N: days for scheduling). Moreover, the number of assigned crews is limited by the workspace and resource constraints. Confronting the constraints on workspace and resource, how to maximize the amount of work completed by the assigned crews is crucial to the optimization of project schedule.
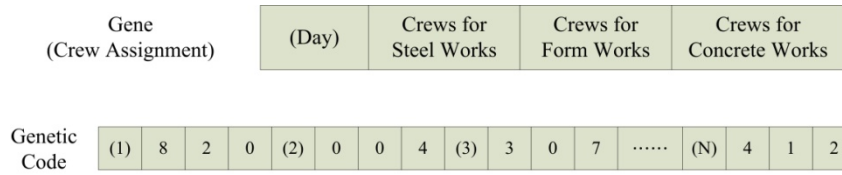
Figure 4 The chromosome structure of crew assignment

Fitness Value
Under workspace and resource constraints, crew assignment is optimized to provide the highest capacity utilization. Therefore, the fitness value of a crew assignment is defined as the higher the capacity utilization, the better the fitness value of a crew assignment will be. In crew assignment, the capacity and the scheduled amount of work should be calculated in order to evaluate capacity utilization. After a genetic string is generated, the capacity that could be provided by the assigned crews may be calculated according to Equation (3):

$$\begin{cases} Capacity\_steel(m) = pro\_steel \times \sum_{k=0}^{N-1} Str(m, 4k+2) \\[2em] Capacity\_form(m) = pro\_form \times \sum_{k=0}^{N-1} Str(m, 4k+3) \\[2em] Capacity\_concrete(m) = pro\_concrete \times \sum_{k=0}^{N-1} Str(m, 4k+4) \end{cases} \tag{3}$$

where N is the working days, pro is the given production rate. Given the capacity, the scheduled amount of work of each work item can be calculated based on the installable building components that are sequenced in OSM. In order to prevent the occurrence of the scheduled amount of work being less than the required amount of each work item, a penalty function is given as Equation (4). Hence, the fitness function is given as Equation (5).

Evolutionary Mechanism
The evolutionary mechanism follows the procedures of selection, crossover, mutation, etc. as mentioned above. After GAs' evolution and convergence procedures, the optimal crew assignment is generated. The resulting schedule is BIM object-based, which integrates the project cost and schedule information. Therefore, it becomes possible for project planners to examine easily relevant resources and costs over a specified time period. In the next section, the implementation and main results are presented.

$$If \ Scheduled\_(m) < \sum_{x=1}^{num} OSM\_(x), Then \ Scheduled\_(m) = 0 \tag{4}$$

$$Max. Fitness\,Value = \left(\frac{Scheduled\_steel(m)}{Capacity\_steel(m)} \right) + \left(\frac{Scheduled\_form(m)}{Capacity\_form(m)} \right) +$$
$$\left(\frac{Scheduled\_concrete(m)}{Capacity\_concrete(m)} \right) \tag{5}$$

4. COMPUTER IMPLEMENTATION-CSIPS SYSTEM

In order to evaluate the viability of the proposed "BIM model based cost-schedule integrated planning," a real-world case is implemented in this study. This study applies the AutoCAD Architectural 2009 (ADT 2009) for the creation of the BIM model, as depicted in Figure 5. This model consists of 5,320 building components. After the creation of the model, the data collected by the model are exported as relational a project database in MS Access. The project database is prepared for import to CSIPS (Cost/Schedule Integrated Planning System) system for project planning.

Figure 5 The PIM model for the case study

The functionalities required for project planning are developed in the proposed CSIPS. There are five major sections in this system:

Project Information: In this section, the BIM model is exported from ADT as an MS Access file and is imported to CSIPS. In addition, general information about the project such as project name, site conditions, subcontractors' information, and owner's requirements are recorded in this section.

Project Estimation: In this section, all project-required tasks are first identified by the coded work items described in the BIM model. For the selected work item, all of the relevant BIM objects will be listed automatically in the table with component type, component ID, and quantity. The information on cost breakdown is derived from the PCC database and is used to estimate the required costs and resources for each work item. The results of the estimates are then recorded in the standard sheets of BOQ and BOM. A specific query based on each floor is possible by this relational database management system.

Project Scheduling (Figure 6): After the identification of project-required tasks, the parameters including the schedule period, the production rate of each work item, the resource and workspace constraints, and GAs parameters should be input for project scheduling. The GAs parameters include population size, mutation rate, crossover rate and number of generation. An optimal construction sequence of building components is then established in OSM. According to this sequence, building components are orderly listed with component ID and the quantity of each required work item. With the inputted parameters and the optimized sequence, planners may formulate an optimal crew assignment. Also, the daily crews assigned to each work item and the scheduled amount of each item will be provided in this section.

Construction Plan (Figure 7): In this section, the building components with associated resources and costs are then scheduled in a bar chart. Information about the cash flow analysis is also provided in this section. The cash flow is estimated based on the weekly scheduled amount of work and then accumulated cash flow is shown in the bar chart. Differing from the

activity-based CPM scheduling method, this study employs an object based scheduling method to formulate a cost-schedule integrated project plan. Furthermore, the work items employed in this research are classified and encoded according to a hierarchical standard code. Based on the standard code of a work item, the information of the corresponding specification and resource items can be obtained. Therefore, CSIPS is also capable of accurately calculating the quantity of labor, equipment and material for the purpose of resource management and control.
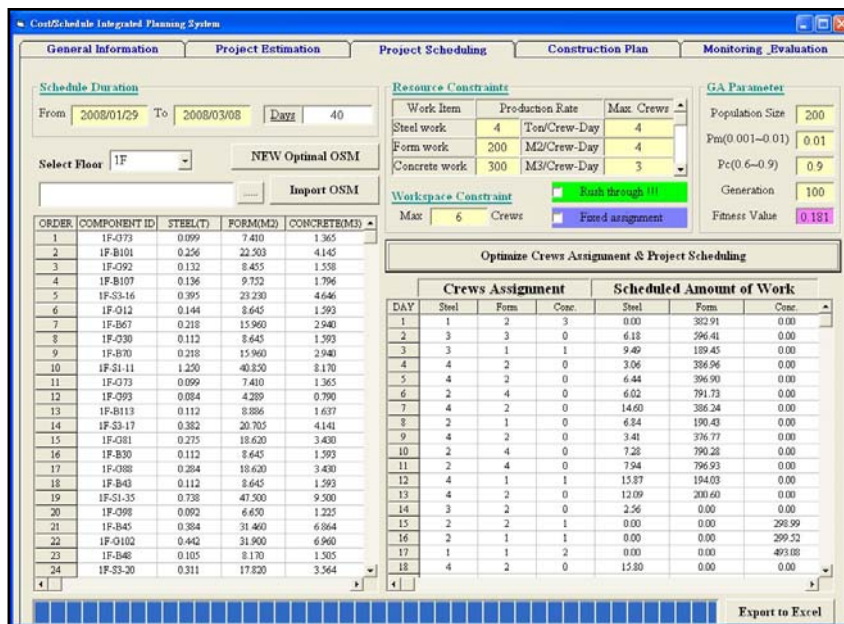

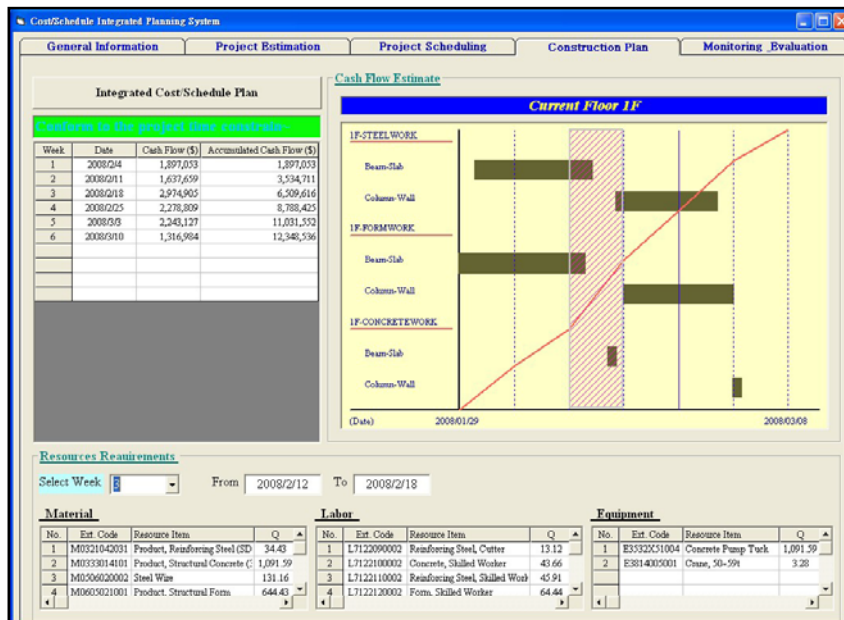Figure 6 The "Project Scheduling" section in CSIPS

Figure 7 The "Construction Plan" section in CSIPS

Monitoring & Evaluation: Effective planning requires continuous monitoring so that the manager can make initial plans and then revise them in order to maintain the proper course toward the main objective. The system is capable of generating daily field records for tracking

the construction work. The information includes the completion of work items, resource consumption, and cost. In project evaluation, the data obtained from "Construction Plan" and construction records, such as budgeted cost, actual cost, scheduled completion, and actual completion will be used in the earned value analysis. The cost and schedule variances assist in evaluating and controlling project risk by measuring progress in monetary terms.

5. CONCLUSION

This paper presents a model-based scheduling method that employs BIM objects to generate information required for project planning. As a core information repository, the BIM model consists of the BIM objects ensures the consistency and reliability of project information processing. From the findings of the case study, this consistent project information model, with associated data regarding functional, material and product information, has the potential to significantly reduce overhead efforts, reduce errors, and improve project performance. Furthermore, the application of the Genetic Algorithms (GAs) helps to optimize the construction sequence and to assist in crew assignment, which takes into consideration the constraints on resource, workspace, and productivity. Results show that by applying the OSM and the GAs to the proposed scheduling method, the project planner can quickly generate an efficient and flexible schedule from the vast amount of BIM objects. Since the BIM objects associate each work item with the resources it requires and its associated costs. The resulting schedule is integrated with project costs, which makes it possible for planners to easily examine relevant resources and costs of a specified time period and provides information concerning the detailed operations throughout the construction process. The proposed CSIPS system has demonstrated the efficiency and feasibility of the proposed approach in project planning and control. The proposed solution is more adequate for general contractors. Since the general contractors have to manage their own subcontractors, laborers, materials, and equipments, many different types of data from many different participants should be managed in an integrated way. In our future research, the MEP (Mechanical, Electrical, and Plumbing) systems will be demonstrated in the BIM model to develop a comprehensive project information system.

6. ACKNOWLEDGEMENT

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