

# DEVELOPMENT OF STRATEGIES FOR APPLICATION OF 4D MODELING IN CONSTRUCTION MANAGEMENT

Yang-Taek Kim <sup>1</sup>, Chang-Taek Hyun <sup>2</sup>, and Kyo-Jin Koo <sup>3</sup>

<sup>1</sup> Ph.D. Candidate, Dept. of Architectural Engineering, University of Seoul, Seoul, Korea

<sup>2</sup> Associate Professor, Dept. of Architectural Engineering, University of Seoul, Seoul, Korea

<sup>3</sup> Assistant Professor, Dept. of Architectural Engineering, University of Seoul, Seoul, Korea

Correspond to [nicehome@freechal.com](mailto:nicehome@freechal.com)

**ABSTRACT :** In many construction projects, progress and efficiency are hampered by poor communication of discipline-specific models. For example, architects use 2D or 3D CAD models and builders use CPM diagrams, Gantt charts, and spreadsheets to show their view of the project. Nowadays, advanced computer visualization tools, 4D CAD or VR, can show these disparate models to understand cross-disciplinary impacts of design and construction decisions. In Korea, several leading companies have tried to apply these tools to their pilot projects from the design phase to the maintenance phase. These companies have expected that more project stakeholders could understand a construction schedule more quickly and completely with 4D visualization than with the traditional construction management tools. However, modeling of the 4D CAD or VR can be quite time-consuming and expensive to generate manually and has therefore limited the spread and use of these models. In order to adopt widely those models in construction industry, the areas that those tools could support to take large benefits in diverse functional areas of construction management need to be analyzed. In this study, researchers analyze the usefulness and limitations of the 4D models and VR in the construction industry, develop the strategy of application priority, and improve the 4D modeling method.

*Key words :* 4D CAD, Virtual Reality, 4D Modeling

## 1. INTRODUCTION

A 4D Model is a visual tool for construction management, for example a Virtual Reality (VR) or a 4D CAD. It combines 3-dimension model with activities of the schedule to display the progression of construction over time.

In Korea, there are a lot of techniques which are used to support planning of construction project such as bar-chart, LOB, and S-curve. But they just have used it only to show and to report the progress, not to control the project with regard to the integration management during the project life cycle. This kind of a schedule is not a particularly good communication means for individuals having different background. It results in a poor communication between builders and designers. For example, designers use a 2D CAD and builders use a spreadsheet or bar chart to show their view of the project. So, those tools couldn't support the project integration management efficiently.

Nowadays it is essential to build trust between project parties and give the owners and users possibility to analyze and give feedback of the construction process plans. An advanced computer visualization tools, 4D CAD or VR, can show the integrated management tools to understand cross-disciplinary impacts of design and construction decisions.

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more project stakeholders can understand a construction schedule more quickly and completely with 4D visualization than with the traditional construction management tools.

## 2. MODELING METHODOLOGY

### 2.1 Automation Approach

'Automation approach' involves applying algorithms to automatically generate 4D models. It refers to computer applications where a reasoning engine or engines together with construction operations knowledge are able to interpret 3D geometric data and produce process plan showing how the building can be constructed [1]. This approach is not applicable in present. However, in the future planner can generate 3D components that are linked to activities, calculate activities durations with information in database, and automatically generate schedules from 3D model that represent the physical scope of work.

### 2.2 Linking Approach

'Linking approach' involves linking the 3D CAD components to the schedule activities to generate 4D models. There are the various modeling processes: The first one is using commercially available software such as Alias Wavefront, AutoCAD, Primavera, and Jacobus Schedule

Simulator. The second one is using commercial tools with customized add-ons such as a visual-basic macro in Excel and a set of MaxScript in 3D Studio Max. The Last one is using a new prototype tools that were developed with Java Applications or a Java Applet and the like. In this approach, designs and schedules have to be done and we do not need to create the 4D model all over again [2]. So, basically generating 4D model do not cause much additional expensive. For that reason this approach is the area where the focus of industrial applications probably will be.

### 2.3 Lego Approach

'Lego approach' involves using the VR to generate 4D model, in other words a product model. Every component of building, such as a door or a wall, has various contents. In the model all information is integrated into the component. And the construction component is visualized and information on materials, quantities, costs, location, placement and even the data of installation is provided [3]. From that model it is possible to move over to the three dimensions like a 'Lego' or even to the fourth dimension, as the schedule management is taken into consideration.

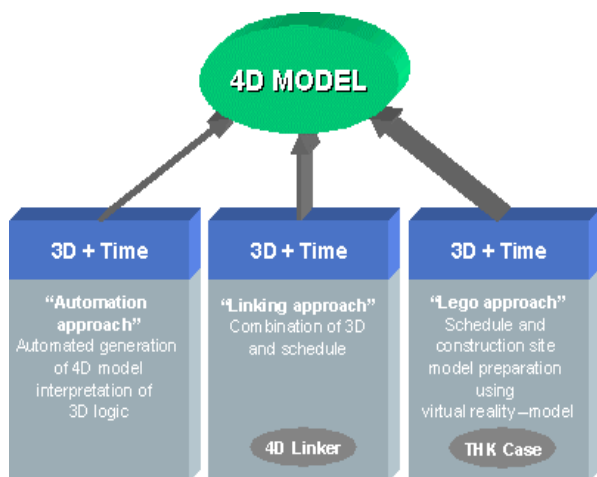


Figure 1. 4D Approaches [1]

### 3. BENEFITS OF 4D TECHNOLOGIES

Through sharing of 4D model, project stakeholders benefited from the improved design quality, shorter design cycle time, and the minimized data re-entry. In spite of schedule constraint, the project team could generate some alternatives. Building on the resulting efficiency (60% of the conventional practice) and time-savings (50% of the conventional practice) during the early conceptual phase, the project team could conduct in-depth life-cycle studies to improve building performance. The 4D approach could benefit design quality, life-cycle facility performance, near and long term cost, budget control, and the design and construction process [4].

The 4D technologies could enable planner to generate various views of this 4D model to clearly communicate the spatial and temporal aspects of construction schedule to all project participants. Project stakeholders could use 4D model to manage and minimize risk throughout all stage of a

construction project, to rapidly explore design and construction alternatives, to make improved understanding of design and schedule, and to receive feedback from a broad range of others. And 4D technology could provide a view of a project database to store and maintain the information of building component and construction activities. This database could support other design and construction [2].

The 4D model is helpful in finding scheduling problems that were overlooked in schedules represented with the traditional bar chart or network diagrams. First, it is not easy to spot the problem in the bar chart schedule because the activities are performed by different subcontractors and are therefore placed in different parts of the schedule. However, using the 4D model, supervisors immediately detected the faulty sequence logic. Second, it might be a problem to have many workers crowding an area. The 4D model helps illustrate such situations so that the affected parties can make appropriate decision. Third, in bar chart schedule it is quite difficult to notice that work schedule in one area of the chart conflicts with work schedule in another section of the chart. With the 4D model managers were able to identify this access problem right away [5].

Time-space conflicts create a variety of problems such as delays in activity onsets, reduction in productivity, and addition of non-value re-works. Akinci uses 4D product model for work space representation to identify and analyze time-space conflict situations. The 4D model is useful to improve the reliability of project schedules, increase efficiency at their job sites, reduce project delays, and make proactive decisions about space management [6].

## 4. PREVIOUS STUDIES

### 4.1 In Korea

Cho [7] proposed the interference management system based on 4D CAD to make the flexible response and preliminary verification against the interference problems in the sub-structure work. It was useful to reduce trials and errors during construction phase because it could show the interference problems at design phase through virtual reality.

Jang [8] proposed the virtual reality for steel construction management system which enables a project manager to control schedule and cost of the project in web based virtual reality space. The system had the advantages of the availability of 2D drawings by converting 2D model to 3D model and lower cost to build the virtual reality model than other 4D CAD tools.

Lee [9] proposed the automated generation module which generates a few schedule alternatives based on information of 3D components. It was useful to reduce the efforts of re-linking of 3D components and construction activities because it could support to select the best alternative of all others so the changes would be reduced.

Kang [10] analyzed the limitations of the 4D concept and proposed an improved method for developing 4D system through a comparative analysis of representative 4D system that were developed up to date.

## 4.2 In Foreign Countries

CIFE (Center for Integrated Facility Engineering, Stanford University) is the representative research center for 4D models [11]. The 4D research group of CIFE has tested the usefulness of 4D models through many case studies of projects used 4D model. And the research group has been formalizing the knowledge necessary to build 4D model and has developed a methodology that guides project planners in generating 4D model. Finally they proposed the functionality that is needed in next generation 4D environment, as well.

VTT (Technical Research Center of Finland) is focusing on the applications of virtual reality technology for building construction [12]. Their main objective is to gain understanding of possibilities and cost/benefit ratio of VR and to develop innovative prototypes and industrial demonstrators of VR technology for industrial applications.

VCSR (Virtual Construction Simulation Research Group) was part of the construction management group of Strathclyde university's civil engineering department [13]. They have simulated many kind of project including temporary structures. But now I can't contact web site so I don't follow how it is nowadays.

## 5. APPLICATIONS IN THE INDUSTRY

### 5.1 SmartPlant Review - Intergraph

#### (1) Overviews

Intergraph SmartPlant Review is 3D visualization tool and engineering solution for the process, power, and marine industry. Users can review designs and use the 3D model as a graphical interface to access project data linked to the model. SmartPlant has several modules for construction and schedule review, simulation and visual effects, on-site drawing generation, and so on. It runs on typical Intel Pentium desktop or notebook computers with Microsoft Windows 2000/XP operating systems [14].

#### (2) Accessibility

SmartPlant runs on web-based environment so there are no limitations of access by constraints of office network. Project stakeholders who have responsibility of the project can access the model and associated data at any remote location and at any time.

#### (3) Viewing

SmartPlant provides construction sequencing capability and supports two popular planning programs: Primavera Project Planner and Microsoft Project. It associates the activities from project schedule with the components from 3D model manually or automatically. And then, it display the sequence. In display mode, SmartPlant enables users to perform 3D walk-through, fly-through, fly-around, and other path- or dynamics-based motions on real time with high resolution.

#### (4) Data Management

SmartPlant involves 'Linking approach' described in 2.2.

Users can attach any external data file, for instance Microsoft Excel file of material list, to any object in model. So users can simply click and drag the mouse over an object to display object attributes that is data from the database associated with an object. But it is needed the database management program to manage the associations between 3D object and linked data.

### 5.2 4D Project Navigator - VirtualSTEP

#### (1) Overviews

VirtualSTEP founded in 1999. Their products are a series of web-based software applications that collaborate construction scheduling, cost control, and project management through ASP (Application Service Provider) model. VirtualSTEP provides several applications such as 4D Project Navigator, Conflict Coordinator, Project Report, and project Analyzer. All these products are web-based [15].

#### (2) Web-based Management

4D Project Navigator allows for three-dimensional viewing in conjunction with project schedules to create 4D simulation. Users can post 2D drawings to project area on website, where software will combine the drawings and schedule and create 4D simulation of the construction plan, checking for conflicts at the same time. The system also provides a web-based progress update for team members. But there are some barriers. If the net is busy because of the huge data in drawings, schedules, costs, and resources, it takes a long time to connect the website.

#### (3) Viewing

4D Project Navigator visualizes construction progress on website so project team members can identify the status of project wherever connected internet. It provides walk through capability, dynamic progress animation, and snap shop image of project status to project stakeholder.

### 5.3 Visual Project Scheduler - Visual Engineering

#### (1) Overviews

VPS is a 4D CAD based approach to develop a project schedule and cost model. VPS can import data as a DXF (data exchange format) file from different CAD systems. And then, it visually reorganizes the model in a way more suitable for preparing a task list and scheduling. Object in the model can be broken into parts and regrouped as construction objects [16].

#### (2) Scheduling

VPS can prepare a schedule in two ways. First, it can generate automatically activities for all objects in the model. Construction objects became activities and they are automatically correlated with those activities. Second, it can use a scheduling program such as MS Project or Primavera Sure Track. VPS can import activities and relationships form external database of scheduling program. These activities can then be graphically associated to objects in the model.

#### (3) Viewing

VPS can make walk through, fly through, move in, and

around the model simulation simple. While moving through the model, snap shot can be generated and saved as file. The built-in AVI generator can utilize to be included in animated video output.

#### 5.4 fourDscape - BALFOUR

##### (1) Overviews

BALFOUR is a developer and provider of interactive time-based visualization technology solution. They first developed 'fourDviz' in 1998 to control the 4<sup>th</sup> dimension of time within 3D interactive environment, and they recently develop in 2003 a new version of 'fourDscape' that was based on 'fourDviz'. 'fourDscape' is a desktop browser that enable users to visually integrate and analyze multi-dimensional data flows in collaborative environment. For examples, construction schedules can be married to CAD visual models and shared with managers, schedulers, engineers, and on-site contractors over the internet [17].

##### (2) Key Features

fourDscape is a browser/server combo that can co-exist with existing Internet web browser. Users can access remote 4D Portal site, using the same URL/internet address format as existing web servers. Then, the 4D Portal server queries a DB for time-specific content such as schedules, integrates associative data to the 3D model, and sends 4D landscape to the browser.

##### (3) Viewing

It can show the visual landscape with a variety of user-selectable motion models (fly, drive, zoom, etc.) and the VCR-like landscape through time at user-selectable speed. And users also can identify more detailed time-relevant data for selected object in the 4D landscape.

#### 5.5 Schedule Simulator - Bentley

Bentley Schedule Simulator was the industry's first commercially available software for 4D. But now, Bentley doesn't support the functionality of simulating the sequence of construction based on scheduling information in 3D models. They just provide the functionalities of detection, review and management of component interferences in 3D models on web-based environment. It also can link any other data with 3D objects [18].

### 6. LIMITATIONS OF RECENT TECHNOLOGIES

#### 6.1 Barriers in Conventional Designing

In conventional practice, designers sketch, red line, and subsequently assign drafters or CAD-operator to re-enter the design or modifications into the computer. It is just a drawing not an object that can be linked other project information. Furthermore, today's CAD tools are mainly focused on the production of construction drawings and do not offer the functionality needed for 4D modeling. They do not offer an intuitive and easy-to-use object-oriented environment that allows users to build a graphical and informational model.

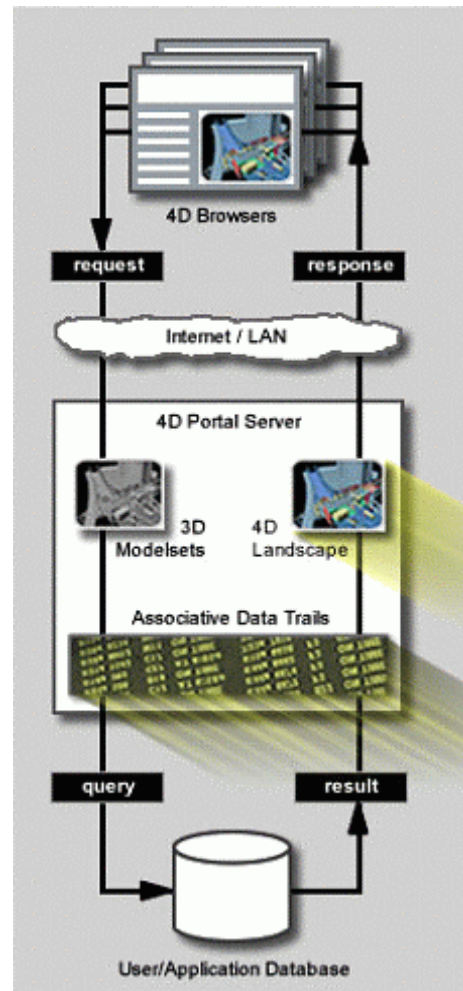


Figure 2. System Diagram of fourDscape [17]

#### 6.2 Barriers in Generating a 3D Model

Designers organize the components in the 3D model focusing on layering the graphical information in the way that facilitates drawing production. This is usually not useful for schedule visualization because the layers rarely correspond to the geometric information that describes the scope of the construction activity. Additionally, many important components, such as scaffolding, lay-down areas, etc., are often missing in the 3D model. The 3D model typically contains only the final components of facility.

#### 6.3 Barriers in Generating a Schedule

Today, schedulers have no way to translate their thinking directly into activities that are linked to 3D components that represent the physical scope of work. Instead, they must create abstract activity and later link the activity to its related 3D components. There are no tools that allow schedulers to create activities and schedule in a 4D environment. But they generate schedules with Primavera, MS-Project, and so on. So, scheduler cannot easily review and make changes to 4D model.

#### 6.4 Barriers in Relating 3D Components to Activities

Today's 4D tools require the manual linking of CAD layer names with activity names or the use of a pre-determined naming convention for activities and CAD layers

so 4D tool can create the link between CAD layers and activities automatically.

### **6.5 Barriers in Updating and Maintaining a 4D Model**

Today, planner, designer, and engineer can't directly update and maintain the 4D model because no 4D tools provide a direct access to the 3D components and schedule contents. So, when design or schedule changes occur, planners have to edit the original contents, re-group 3D model components, re-sequence activities, and re-associate 3D components with construction activities. It is very cumbersome and difficult to update and maintain a 4D model.

## **7. APPLICATION STRATEGY OF A 4D MODEL**

### **7.1 Phased Application for Approaches**

We will have to start the application of 4D modeling with 'linking approach'. This approach can make a model with resent available commercial software such as AutoCAD and MS-Project. There will be not reluctant to apply a 4D model into planner's practice because it won't require them an additional work or cost to generate 4D model.

Next, we will have to generate 4D model with 'Lego approach'. It needs only the product model that is integrated with all information including time without scheduling software. But planner will have to plan with components of 3D model not 2D drawings and have knowledge of construction sequence for scheduling.

Last, 'Automation approach' will be applicable in future. It can automatically generate 4D model and schedule with a reasoning engine or a knowledge-based DB. So, project stakeholders will benefit from the improved design quality, shorter design process, and the minimized data entry.

### **7.2 Change of Design Practice**

In conventional practice, designers sketch by the hands and enter the design into the computer with some CAD programs. It is just a drawing not an object that can be linked other project information. However, to fully maximize the benefits of 4D technology, planner, designer, and engineers will need to change how they produce project data. They should focus their effort on producing and evaluating 'models' instead of 'drawings'. Planners need to represent the design not only as graphical drawing object, but also as intelligent and open information objects that can be linked to other project information. And CAD tools have to change their functionality of placing information by layer of 2D to integrating information by components of 3D.

### **7.3 Construction Based 3D Modeling**

Today, designers organize the components in the 3D model using the layers that focus on arranging the graphic information. These layers can't correspond to the scope of work. It causes the level of detail problems. For example, linking several activities to one layer will not result in the 4D visualization at the level of detail in the schedule. So, designers have to regroup CAD components found several

layers onto a different set of layers or break a component into smaller pieces and put the piece on separate layers. In future 4D environments, designers need to organize the 3D model using construction-specific information like construction area and zones. And it will be needed to automatically add construction-specific contents such as scaffolding, cranes, access roads, and lay-down areas.

### **7.4 Scheduling in the 4D Environment**

Today, schedules are generated in a schedule tool such as P3 or MS-Project. So, schedulers must later link the activities to its related 3D components. However, 4D tools need to allow schedulers to generate the schedule content within 4D environment, thus directly associating the activities in the schedule with the 3D components. And it will be possible to automatically generate schedules from 3D model using a reasoning engine or a knowledge based database.

### **7.5 Documentation of the Rationale for Association**

It is very difficult to update and maintain a 4D model because the reason for the creation of activities, their associations with 3D components, and their sequence relationships is not recorded in the 4D model. So, designers have to edit the original contents and re-perform many of the modeling tasks. The one solution of this problem is to reduce the design changes through substantial adjustments to the model when model was generated. But a design changes are inevitable in the construction projects. It is needed to document the reason for each association in the 4D model. So anyone who wants to change the model can re-perform the modeling tasks without missing important associations.

## **8. CONCLUSION**

Nowadays it is essential to build trust between project parties and give the owners and users possibility to analyze feed-back of the construction process plans. An advanced computer visualization tool, 4D CAD or VR, can give the integrated management tools to understand inter - disciplinary impacts of design and construction decisions.

In Korea, several leading companies have tried to apply these tools to their pilot projects from the design phase to the maintenance phase. However, modeling of the 4D CAD or VR can be quite time-consuming and expensive to generate manually, so the difficulty and cost of creating such model is blocking their widespread adoption. In this research, the usefulness and limitations of the 4D models in the construction industry are analyzed, the strategy of application priority is developed, and improvement method of 4D modeling is suggested.

Researchers find out, in spite of lots of benefits, the 4D technology has some limitations that prevent industrial applications for construction. Major barriers are as follows: Barriers in conventional design practices, barriers in generating a 3D model and a schedule, barriers in relating 3D components to activities, and barriers in updating and maintaining a 4D model.

Researchers propose the strategies for application

priority of 4D approaches. It is necessary to develop the phased application for 4D approaches. With regard for being reluctant, we have to start the application of 4D model with linking approach. Then lego approach would be applicable, and automation approach will be developed and adopted lastly.

Researchers also suggest that the practices of a planning, designing, scheduling, and controlling have to be changed. Planers need to organize the 3D model using construction-specific information like zoning or temporary work. Designers have to represent their thinking with 3D objects not with 2D layers. Schedulers need to generate schedules in 4D environment that can directly associate the activities with its related 3D components. Finally, the planer, designer, scheduler, and the other project stakeholder have to document the reason for all association in 4D model. These documentation will be helpful to reduce the re-work of modeling when design changes occur.

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