

# THE INFORMATIVE VISUALIZATION METHOD OF THE 4D CAD MODEL

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## Abstract

A novel construction schedule presentation called the 4D CAD model is able to explicitly demonstrate the construction sequence and working space in 3D visual. However, it still has some shortages and is used as a supplementary presentation. This research identifies the deficiencies of the visualization of the 4D CAD model and proposes improvements. The presentation abilities of the existing 4D CAD model are analyzed and compared with the other conventional methods, namely Gantt chart, network diagram, and calendar. Four aspects of the visualization are addressed, namely the overview of a schedule, the duration of an activity, the relationship of an activity, and the project progress tracking. The proposed improvements employed different visual properties of 3D CAD objects such as color, line weight, and line type to represent the different activities' performing statuses. This development can enhance the visualization of the 4D CAD model and provide a more informative construction schedule. It is anticipated that the 4D CAD model with these enhancements can substitute for conventional presentation methods of a construction schedule.

**Keywords:** 4D CAD Model, visualization, construction planning, schedule, simulation

## Introduction

Planning and control are important tasks for successfully managing construction projects. A plenty of information, regarding the descriptions of what tasks to be done and when, is generated at this stage. Currently, there are many presentation methods to deliver this information to users such as the Gantt chart (or bar chart), the network diagram, and the calendar. The presentation method of construction schedule can heavily affect the comprehension of users.

It is also a necessary tool for communication and collaboration among the project team. The 4D CAD model is an innovative method of presentation (Cleveland, 1989). It is the integration between 3D CAD objects representing construction activities and their scheduled time (3D + time). It simulates and visualizes the construction scenes in a time sequence. The result is a movie or an animation which simulates the construction components

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adding up as planned sequences from the project commencement to completion. The 4D CAD model helps create a conceptualization and comprehension of construction processes and working space required (McKinney and Fischer, 1998). Kamat and Martinez (2001) used a 3D visualization technique to simulate construction operations for a design purpose. The 4D CAD model, however, still has some limitations on implementation. These limitations are tedious tasks such as 3D CAD modeling, and linking between 3D CAD objects and construction activities; lack of document reporting formats; and deficient visualization. This research aims to improve the 4D CAD model and overcome its limitations on the visualization issue.

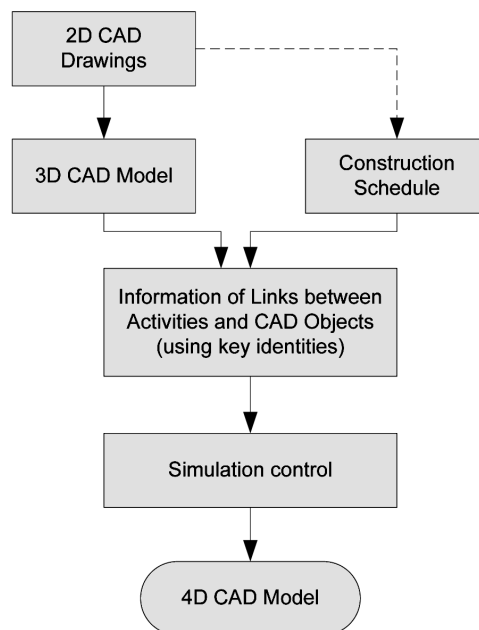
A construction schedule contains a variety and plenty of information which mainly is the description of what is to be done and when. Many schedule presentation methods have different abilities for presenting this information to the users. Although the 4D CAD model has an outstanding ability for presenting construction activities in visual 3D, it has some weaknesses. This paper addresses four deficiencies on the visualization such as the schedule overview, activity duration, relationship, and project progress tracking. Unless these limitations are overcome, the 4D CAD model cannot entirely be a substitute for the conventional schedule presentation methods i.e. Gantt chart, network diagram, and the calendar. It is being used as a supplement to the conventional schedule presentation methods. Users who use the 4D CAD model still need to work with other schedule presentation methods. Therefore, it adds a lot more work for the users.

This research addresses on the visualization of the 4D CAD model technique. It aims to enhance the visualization and to improve the presentation ability of the technique. The enhancements of the 4D CAD model are designed and the prototype is developed and evaluated. It systematically manipulates the visual properties of the 3D objects to represent the specific meanings. This helps users to effectively and efficiently perceive more information of construction plans. It is anticipated that these improvements will help complete the visualization of the 4D CAD model

and encourage the use of this method more widely.

## Reviews of the 4D CAD Model

In practice, construction schedules and drawings are created at different times by different people. Construction schedules provide information about time aspects and activity relationships. Drawings are normally prepared in two dimensions. They provide graphical information of building components and scopes of construction activities. Construction teams use both of these information sources to understand and execute their work. However, this understanding occurs by individual implicit interpretation. They could understand differently or misunderstand. This leads to collaboration problems and conflicts on sharing resources. The 4D CAD model can overcome these problems because it bridges the two separate information sources. It helps create explicit visual perceptions. It can be an effective collaboration medium for construction teams.



**Figure 1. The development procedure of the 4D CAD model**

The 4D CAD model can be generally developed using the following procedure (Figure 1): prepare 3D CAD model from the 2D CAD drawings, arrange a construction schedule, link 3D CAD objects with construction activities through linking keys (e.g. activity name, layer), and create a simulation control and a visualization. Koo and Fischer (2000) studied the feasibility of implementing the 4D CAD model on commercial construction projects. They concluded that it is a potential tool to accelerate the understanding of construction work. It helps discover errors, omissions, or inconsistencies in construction plans, and evaluate the constructability of the planned sequences. It also analyzes the congestion and accessibility of working space. These problems are difficult to detect via a Gantt chart because construction activities are represented by textual names and duration bars. The 4D CAD model represents construction activities as virtual 3D objects which can effectively convey space information (Akinci *et al.*, 2002).

McKinney and Fischer (1998) have suggested three potential improvement directions of the 4D CAD model, namely connection, analysis, and visualization purposes. Firstly, the connection purpose is the improvement of the linking methods between 3D CAD objects and the construction activities during the model development procedure. 3D CAD objects can be manually selected to relate with individual activities in a construction schedule. This is done through programming dialogue boxes. Dawood *et al.* (2002) developed an integrated database to store the connection information. The database was designed using Standard Classification Methods (Uniclass). For another method, proper 3D CAD objects are grouped into different layers or blocks and later they are automatically matched with different individual activities in a construction schedule through the rule-based programming. Wang *et al.* (2004) employed a work breakdown structure template to link with 3D CAD objects. Their 4D CAD model created a 2-way data exchange mechanism with the schedule. The interactive linking method combines together the functions of modeling 3D CAD objects and

arranging a construction schedule. Every component that is being modeled is also linked to a construction activity through a key identity at once.

Secondly, the analysis purpose is the improvement in various applications. The 4D CAD model is a potentially powerful tool for analyses and decision support. The analytical applications are on topics such as time, working space, sequences, and temporary structures. The ability to simulate virtual construction scenes can bring awareness and foresee any error or unsuitability in the schedule. For examples, Akinci *et al.* (2002) applied the 4D CAD model on the congestion of working space; Chau *et al.* (2005) applied it for the construction site and resources management; Ma *et al.* (2005) used it for planning site layouts at different construction stages; Jongeling and Olofsson (2007) proposed a location-based schedule method which can be enhanced with the 4D CAD model to improve the work-flow of construction activities.

Lastly, the visualization purpose is the improvement of the model presentation as an enlightening information medium. Additional annotations, graphics, symbols, colors, and texts are employed to give more necessary schedule information. They can be presented in an easy-to-interpret format. They help users obtain a quick and thorough comprehension. For example, different colors can distinguish different activities' performing statuses such as not-started, in-progress, or finished. They can also distinguish critical or non-critical activities. 3D CAD objects of temporary structures and equipment are added to simulate a more realistic construction scene so that users can experience the coming work before it starts. The previous research emphasized the first two improvement directions while the improvement of visualization is still lacking and not receiving attention. On the other hand, an appealing and informative visualization of the model should contribute to a more widespread use of the 4D CAD model. It could finally become a standard method of schedule presentation. Thus this research addresses on this purpose.

## Conventional Presentation Methods of Construction Schedules

A construction schedule communicates a lot of information regarding the construction project and activities. A construction team uses a plan to understand and collaborate on their work. The impressiveness of the schedule and information shown can help the team to perceive all this information rapidly and correctly. A few presentation methods of construction plans are commonly used. They are reviewed as follows and this review will give a reference for comparison with the presentation of the existing 4D CAD model. The review also shows that there is no perfect presentation method. Every method has its own advantages and disadvantages. The advantages of these methods will be used to direct the improvements.

1. A network diagram (precedence diagram) is a presentation method that uses a box to represent a construction activity. The box is divided into sub-boxes used for different pieces of information such as activity name, duration, earliest start and finish time, latest start and finish time, total slack, and free slack. A pair of boxes is linked together with an arrow to represent a relationship. This arrow can represent many types of relationships such as start-to-start, finish-to-start, finish-to-finish, and special relationships with lag or lead time. Many of these boxes and arrows are connected to form a network.

A strong advantage of the network diagram is that it can clearly present complex relationships of construction activities. It clearly presents the identity of construction activities through individual boxes. The layout of the box can be used to present many types of information. Also, it assists a manual calculation of the scheduling process or the CPM. Although the network diagram can show the overview of the plan, it requires a large space. A disadvantage is that the whole network of a construction project commonly fills more than 1 page. Most information is presented in a textual format which ineffectively stimulates people's perception.

2. A Gantt chart is a presentation method that combines a table and a histogram. The table part is used to present many different pieces of

activity information. A row represents an activity while many of its columns are used for that activity information. Each activity has its own bar to represent the performance schedule. The length of the bar represents the activity's duration. In addition, arrows are used to connect between these bars to represent the activity's relationships.

The Gantt chart is a very commonly used method. Its strong advantages are that it clearly presents the identity of activities; it can present many pieces of activity information the same as, or more than, the network diagram does; it can also present the work breakdown structure of the project and group levels of activities; and it can visualize the planned duration of an activity through its bar length. Another set of bars can be added beneath the original baseline bars to present the actual-done schedule of activities. In addition, the Gantt chart can be used for the purposes of tracking progress. It can visually compare the planned against the actual-done schedule. It is in a compact size with a neatly organized table and chart formats. It can give a good overview of the plan. However, it ambiguously and confusingly presents the activity's relationships because the arrows are usually overlaid on each other.

3. A calendar is a presentation method that employs an ordinary calendar form to present to-do activities. An activity is represented by a bar. The activity bar is continuously drawn to pass through the performing dates as planned. A few textual details of the activity can be placed within the bar.

A strong advantage of this method is that it clearly shows what activities must be performed on any particular date and how many days are assigned to do an activity. This presentation is tidily organized but its size will not be compact if the project is taking a very long time. It is unable to present the activity's relationships.

## Deficiencies of the Presentation of the 4D CAD Model

The 4D CAD model has been developed by many different researchers; however, there

are some common characteristics of the visualization. The model runs the simulation from the project commencement to the completion. At the beginning of the simulation, the result screen is empty. Then, the model gradually displays construction components in relation to the scheduled sequence. At any simulated construction stage, the model shows only components which are related to 'finished' and 'in-progress' construction activities. 3D CAD objects of these components are set to 'Show' status (meaning display on the screen). The model does not show the other components which are related to 'not-started' activities and 3D CAD objects of these components are set to 'Hide' status (meaning off-display on the screen). At the end of the simulation, the model displays the whole building's components.

One difference in the visualization of the existing developments is the use of 3D CAD objects' colors. Some developments (McKinney and Fischer, 1998; Wang *et al.*, 2004; Chau *et al.*, 2005) used various colors for different activities or component types. They also allowed users to customize the objects' colors. Others (Sriprasert and Dawood, 2002) used two different objects' colors to distinguish the performing statuses of the construction activities into 'in-progress' or 'finished'. The newly added 3D CAD objects were assigned with the color red which represented in-progress activities. When these activities were completed, the model turned their 3D CAD objects to the color green which represented finished activities. They also used the 4D CAD model to present the baseline schedule and the tracking schedule but these simulations ran on separate occasions.

The existing developments also have some differences in the user interface. The 4D CAD model requires integration between design and planning information. The user interfaces of the developed systems were based on the commercial 3D CAD and planning software such as AutoCAD and MS Project. Users had to switch between the two software applications to obtain all information they wanted. However, some developments had their own interface. McKinney and Fischer (1998) developed a prototype system in the AutoCAD environment.

They combined the network diagram view within the 4D model's result screen. Chau *et al.* (2005) used separate interfaces for the 4D CAD and the schedule. They also developed the template Work Breakdown Structure (WBS) system to be a bridge between the 3D CAD model and the schedule (Wang *et al.*, 2004). Chantawit *et al.* (2005) used textual annotations to give appropriate safety information for the construction activities. They developed a separate interface from the 4D CAD for this safety information. The safety library and safety plan were stored in a database that would support their system.

The 4D CAD model presents a construction plan via an animation. It simulates virtual construction scenes and processes in 3D graphics. Strong advantages of this method are that it gives a perceptive visual work scope and sequence. It can give a virtual experience of the work to the team. However, the visualization of the 4D CAD model is still unable to present all the information of a construction plan. Compared with the conventional presentation methods reviewed above, four deficiencies of the 4D CAD model are delineated. Table 1 summarizes a comparison of the presentation abilities of the available methods.

1. The overview of a schedule – the 4D CAD model presents a schedule in a movie format. The playback of the movie is running continuously. The simulation of the 4D CAD model runs by means of gradually adding up (displaying on the screen) a new group of 3D CAD objects which are representing the commencing activities. Users will see any scene in just a moment and then it keeps changing. They cannot see the overview of a schedule. Therefore, they tend to perceive the sequence rather than the overview of the project work. Unlike a still picture medium such as a Gantt chart, users can see the whole page all the time. They can read line by line or quickly scan through it or skip back and forth. They can better conceptualize the whole content of the schedule. When the project is large and complex, the overview of the schedule can help to efficiently comprehend the whole scope of the project work.

2. Activity duration – the activity duration is not directly presented in a quantitative manner. The duration of an activity is interpreted via the length of simulation time. It is the time for which its corresponding 3D CAD objects stay in the ‘in-progress’ status. For example, if the color red is used to represent the in-progress status (Sriprasert and Dawood, 2002), an activity which can stay red longer has a longer duration. It is difficult to evaluate and compare the durations of activities, particularly when the project is large or the activities have very different start times. On the other hand, the Gantt chart can illustrate the activity duration via both a length of bar and a number. The activity duration is important information of the schedule. It helps users justify the reasonableness of the schedule and the difficulty of an activity.

3. Activity relationship – the 4D CAD model cannot directly present the activities’ relationships. There is no arrow used. Relationships are presumably interpreted via the sequence of the activities’ appearances. The start of an activity occurs right after the finish of another activity or the status colors of the two activities change synchronously. These could mean the finish-to-start relationship of these two activities. However, two activities which have adjacent performing time need not to be related together. Also, the distinction between a predecessor and a successor is difficult to perceive. The other types of relationships such

as start-to-start, finish-to-finish, and relationship with lag or lead time are even more difficult to be presented via the 4D CAD model.

4. Project progress tracking – during the actual construction, a plan is used for tracking the project progress. The Gantt chart employs two different sets of bars to visually compare between the planned and the actual-done schedules. The network diagram uses more space within an activity box to present the actual-done data. Despite those, the 4D CAD model is still lacking a certain method for this presentation purpose. Its application is restricted to only the planning phase. Sriprasert and Dawood (2002) used the two separate sets of schedule data to create two distinct 4D CAD simulations; however, it is difficult to perceive the variances between the two schedules.

## Proposed Enhancements and Prototype Development

A prototype of the 4D CAD model is developed on a residential condominium project. The model development followed the procedure shown in Figure 1 and described in this section. The 3D CAD is modeled using the Autodesk’s AutoCAD 2007. The 3D model is developed from the available 2D drawings. Some details of the building are excluded and simplified to suit the research work. The schedule is prepared using the Microsoft Project 2003. The 3D CAD

**Table 1. A comparison of abilities of different presentation methods**

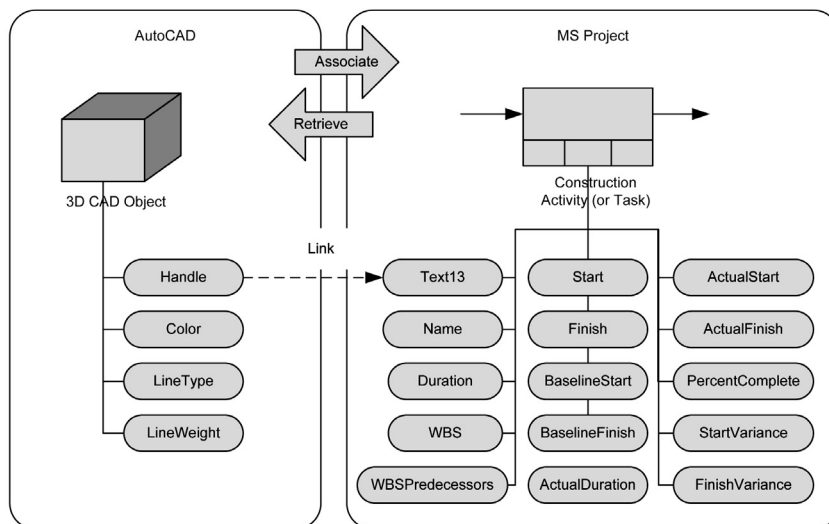
Presentation abilities	Network diagram	Gantt chart	Calendar	Exist.4D CAD model
Overview	Fair	Good	Fair	None
Activity Identity and Scope	Fair	Good	Fair	Fair
Activity Duration	Fair	Good	Fair	Fair
Relationship	Good	Fair	None	None
Project Progress	Fair	Good	None	None
Construction Sequence	Fair	Fair	None	Good

*Remark: distinguishing abilities into three levels as Good – Fair – None*

objects are linked with the corresponding construction activities through the linking keys. The 'Handle' property of 3D CAD objects is used as their referencing identity. The Handle of an individual object is a unique and persistent combination of characters. The developed prototype has a total of 838 3D CAD objects representing the whole construction project. Their Handles are retrieved, transmitted, and correspondingly recorded in the 'Text13' property of activities. The 'Text13' provided in the MS Project is a read/write text associated with an individual 'Task' (or a construction activity). Since both AutoCAD and MS Project have supported the Automation interfaces and have a Component Object Model (COM), a VBA code can be programmed within the AutoCAD to create an ActiveX object of the MS Project application. As a result, every 3D CAD object in the AutoCAD has its associated task in the MS Project. The simulation control of this 4D CAD prototype is developed using VBA and AutoCAD's object model. The visualization is exhibited within the AutoCAD while the corresponding schedule information

is simultaneously retrieved from the MS Project through the linking keys. Figure 2 shows the linkage concept for the model development and the objects' properties of both applications utilized in the development.

This research proposes some improvements according to the deficiencies addressed in the previous section. Graphic and textual annotations and various colors of 3D CAD objects are employed to enhance the presentation abilities of the 4D CAD model. Some visual properties of 3D CAD objects i.e. Color, LineType, and LineWeight are used for representing many different performing statuses of a construction activity. Some schedule information of an activity is used for the visualization and the simulation control of the developed 4D CAD model i.e. Duration, WBS, WBSPredecessors, Start, Finish, BaselineStart, BaselineFinish, ActualDuration, ActualStart, Actual Finish, PercentComplete, StartVariance, and Finish Variance. Also, additional interfaces are used to provide some retrieved schedule information without switching between AutoCAD and MS Project Applications. This schedule information



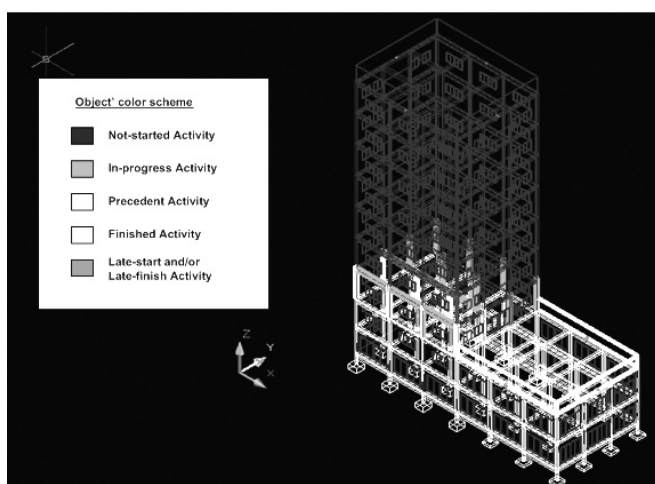
**Figure 2. The created linkage between a 3D CAD Object and a construction activity, and their objects' properties utilized**

complements the understanding of the users. It is anticipated the improved model will complete some missing information of the schedule. The proposed improvements are explained and demonstrated below.

1. The overview of a schedule is presented with the display of all the construction's objects throughout the simulation. At the beginning of the simulation, all 3D CAD objects are displayed in a dark color such as grey which is similar to the background color (i.e. black). These grey color objects represent the 'not-started' construction activities. Then, the color of the objects is gradually and sequentially changed according to the activity's performing status. This is to replace the method of hiding and displaying the objects. All 3D CAD objects are displayed in the 3D-Wireframe visual style. This visual style uses lines and colors to represent every object's boundaries. Hence, users can see the overview of the construction work at all the simulated time. Figure 3 shows a snapshot of the simulation of the progressing project. All construction components are shown but they are in different colors. The higher tower zone, walls and windows are grey. It means that they are a part of the construction project but have not yet been started. Users can be aware of the work

content and context of the project. They can evaluate more efficiently whether the seen construction sequence is appropriate. They can be consistently reminded of the remaining work and also the completed work.

2. The activity duration is presented with additional interfaces. A Dialogue Box named "Activities in Progress" is used to present some important information of the in-progress activities. The in-progress activities which are the focus of attention are provided with more textual information. This explicit information is such as a WBS code which represents the unique identity of an activity. The duration in a unit of time (day) and its percentage of the total project time are shown. Also, the graphic bar which represents the length of duration is provided alongside. The predecessors are provided as the WBS codes of all predecessors of the corresponding activity. This information in the Dialogue Box changes according to the current in-progress activities throughout the simulation time. Figure 4(a) shows two in-progress activities, namely activity 5.3 and 5.4 in the "Activities in Progress" Dialogue Box. The activity 5.3 has a 3-day duration which accounts for 0.8% of the total project time. The activity 5.4 has a 4-day duration which accounts for 1.0%



**Figure 3. The construction project case demonstrating the purposed enhancements and the object's color scheme**



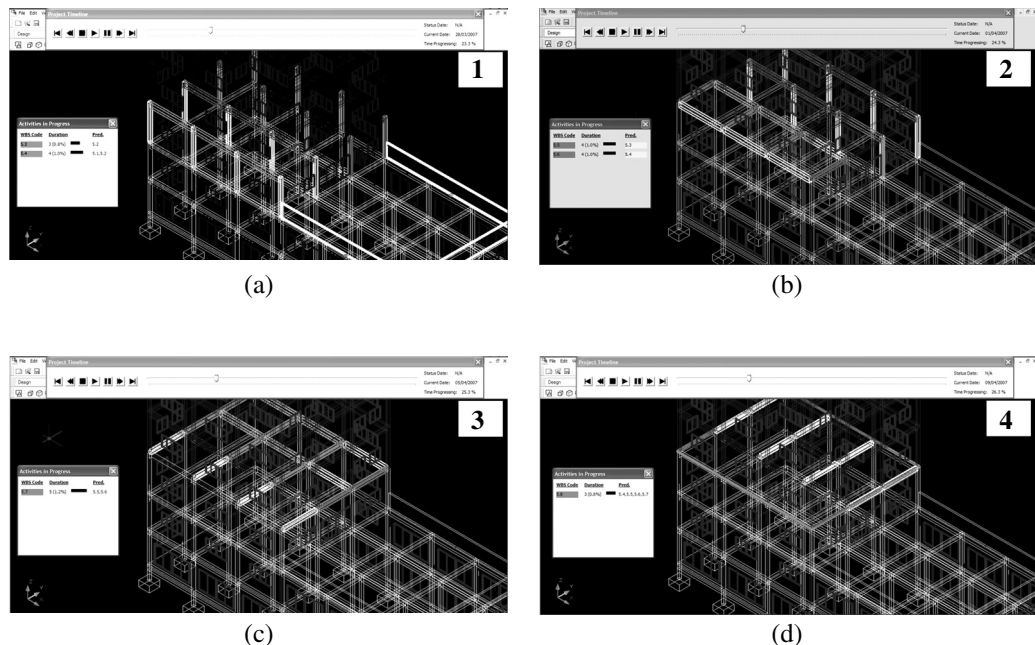
of the total project time. Both activities are also provided with individual duration bars. Users can perceive this duration information and assess the significance of these activities to the overall project schedule.

In addition, a horizontal Slider Control named "Project Timeline" is used to present the project timeline and the progressing project time. The Slider Control shows the simulated current date and the percentage of the progressing time. The ticker of the Slider Control is moving forward to the completion of the project or the end of the simulation. It helps users recognize the project duration and the time position of the current progress. Users can navigate to any particular date as well. Figure 4(a) shows the progressing project on the current date of 28/03/2007 which accounts for 23.3% of the whole project time. Users can be informed that at this point progress is about a quarter of the project.

3. The activity relationship is presented with the use of Color and LineWeight properties of 3D CAD objects. The performing statuses of an activity are categorized into

'not-started', 'in-progress', and 'finished'. The finished activities are further separated into those that are predecessors of the current in-progress activity and those that are not. Different colors are then assigned for these categorized performing statuses: grey for not-started; magenta for in-progress; yellow for predecessors; and white for not-predecessors. The in-progress activities and predecessors are the focus of attention and they convey the relationship information. Both their assigned colors are contrasted with the background color and their 3D CAD objects are given with thicker line weights (0.4 mm.) so that they can be illuminated and highlighted. The line weights of not-started and not-predecessors activities are assigned with a default value of 0.25 mm. Therefore, any 3D CAD object will have a normal sequence of changing colors as grey, magenta, yellow, and white, respectively. Also, the "Activities in Progress" Dialogue Box provides relationship information as the WBS codes of all predecessors of the corresponding current activities.

Figure 4 shows four screen shots of



**Figure 4. A series of screen shots of the enhanced 4D CAD model demonstrating the changes of activities' performing statuses**

different simulation time in sequence. They show that the project is progressing through simulated time while the color and line weight of corresponding 3D CAD objects are sequentially changing according to their changing performing statuses. For example, Figure 4(a) shows that the activity 5.3 (columns group 2) and activity 5.4 (beams group 1) are in-progress so that their corresponding 3D CAD objects are given in magenta. The activity 5.3 has a predecessor which is the activity 5.2 (columns group 1) and the activity 5.4 has two predecessors which are the activity 5.1 (external walls) and 5.2. The corresponding 3D CAD objects of these predecessors are displayed in yellow. The 3D CAD objects representing the bottom part of the building including foundations and the lower tower zone are displayed in white so that they all are the not-predecessor finished activities. In addition to the different colors and line weights of 3D CAD objects, textual information of activity relationships is explicitly provided in the "Activities in Progress" Dialogue Box.

Figure 4(b) shows a screen shot of the succeeding construction sequence. Three events have occurred concurrently. The first event, the activities 5.3 and 5.4 are finished and become predecessors of the new current in-progress activities namely 5.5 and 5.6, respectively. The 3D CAD objects representing the activities 5.3 and 5.4 now change their color from magenta to yellow and still maintain their line weight of 0.40 mm. Simultaneously the second event, the in-progress activities currently are 5.5 and 5.6 and they become the new highlight. The 3D CAD objects representing the activities 5.5 and 5.6 now change their color from grey to magenta and their line weight from 0.25 mm. to 0.40 mm. The third event, the activities 5.1 and 5.2 which used to be predecessors are now not-predecessors and lose the highlight. Their corresponding 3D CAD objects change their color from yellow to white and their line weight from 0.40 mm. to 0.25 mm. All these changes help users to better perceive the relationships among these activities. Figure 4(c) and 4(d) show screen shots of the subsequent construction sequence.

4. The project progress tracking is presented with the use of Color, LineWeight and LineType properties of 3D CAD objects. During the construction stage, the task of tracking the project progress is carried out. Two sets of schedule information, namely baseline and updated schedules are prepared and compared. The baseline schedule which was originally prepared during the planning stage is used as a standard of a comparison. The simulation of the baseline schedule is implemented as stated above. The control of the baseline simulation is the planned start and finish times of the activities. When the project is actually progressing, these planned start and finish times of an activity could differ from the actual start and finish times. The planned time is updated with the actual time, resulting in the updated schedule. Finished activities have already had the actual start and finish time. Therefore, the simulation of the updated schedule uses the actual time as a control. In-progress activities could have a combination of the actual or planned time. In case of not-started activities, their planned time is still used as the control. In addition, the "Activities in Progress" Dialogue Box provides more necessary information from the project tracking and the schedule comparison. This information is such as start variance (SV), finish variance (FV), and percent completion (%Com.). A positive value of these variances means the actual-done time is later than the planned time, and vice versa.

To visualize the project progress tracking, the 'in-progress' activities are further categorized into 'late', 'early' and 'as-planned' executed. When an activity become 'in-progress' and it has the actual start and/or finish time later than planned, it will be defined as a 'late' in-progress activity. On the other hand, an 'in-progress' activity which has the actual start and/or finish time earlier than planned will be defined as an 'early' in-progress activity. The object color assigned for the 'late' in-progress activities is red. The color red is used to give a warning message to users as late activities can bring troubles to the project completion. While 'early' in-progress activities are less serious, the object color assigned for them is green. An 'in-progress'

activity which has the actual start and finish time the same as planned will be defined as an 'as-planned' in-progress activity. The object color assigned for the 'as-planned' in-progress activities is magenta. The highlights for these in-progress activities still are their thicker objects' line weights (0.4 mm.). To differentiate between the simulations of the baseline (planned) and the updated schedules, the manipulation of the objects' line type is implemented. The 3D CAD objects representing the in-progress activities of the baseline schedule have the 'Continuous' (solid) line type while the ones of the updated schedule have the 'Hidden' (dash) line type.

Figure 5 shows the simulation of the updated schedule of the example project. It shows the project progress on the simulated date of 29/03/2007. The "Project Timeline" Slider Control shows the status date on 30/03/2007 which is the date of the latest updated information. This information can be retrieved from the MS Project application's Project property named StatusDate. The "Activities in Progress" Box shows additional quantitative tracking information, namely SV, FV, and %Com. The activities 5.3 and 5.4 are currently in-progress. The activity 5.3 started 1 day later than planned and it will be finished two days later than planned. It currently has a 25% completion progress. The activity 5.4 started and will be finished as planned. It currently has a 50% completion progress. This visualization helps users evaluate the actual construction performance

compared with the baseline and obviously detect the problem areas. Users can be aware of the late activity and assess its impact. They also can be informed about the number of days late.

## Evaluation Results

The application of the prototype of the 4D CAD model showed that the proposed enhancements could help users effectively perceive all necessary schedule information on the visualization. Users could gain visual perception and experience of not only the construction sequence but also the construction schedule which was presented in four aspects, namely the overview of the schedule, the activity duration, relationship, and the project progress tracking. These aspects are as important as the construction sequence. The overview helps remind users of the content and context of the whole project work. It also persistently shows what has been done and what is remaining. The duration and relationship indicate the significance of an individual activity. They enable users to assess the sensibility of these planned values. Lastly, this enhanced 4D CAD model recognizes both the baseline and updated schedules so that it can be used for the project progress tracking purpose. This extends the usefulness of the 4D CAD model to cover both planning and construction phases.

A methodology of these enhancements was developed in this study. The performing statuses of a construction activity was meticulously categorized into 'not-started',

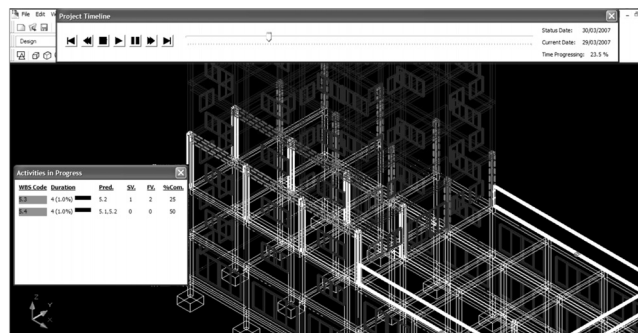


Figure 5. The enhanced 4D CAD model for the project progress tracking

'as-planned in-progress', 'late in-progress', 'early in-progress', 'predecessor-finished', and 'not-predecessor-finished'. These various statuses were used to express schedule overview, activity relationship, and project progress tracking. Visual properties of 3D CAD objects such as color, line weight, and line type were employed to represent the different activities' performing statuses. The distinct combination of color, line thickness, and type could give different levels of emphasis and highlight on construction activities. Additional interfaces such as dialogue boxes were used to provide the other necessary schedule information including activity duration, relationship, and project progress tracking.

Despite these abilities, some limitations of the enhanced 4D CAD model and possibilities are recommended for future research studies. The visualization of the 4D CAD model displays 3D CAD objects on screen that are clustered into groups of different colors. The identity and scope of each individual activity are difficult to distinguish. Although special relationships of construction activities including start-to-start, finish-to-finish, lag, and lead time could be visualized and provided via the enhanced 4D CAD model, they may not be clearly distinguished from a common finish-to-start one. Other activities' statuses such as critical and non-critical or some filtering features can also be further developed on the 4D CAD model using a similar methodology. Other features of planning and scheduling can be included in the CAD application so that the development of the 4D CAD model can be independent from the scheduling application. The future CAD application will become a complete integrated working station for design, drafting, planning, and visualizing. Moreover, many forms of multimedia including sounds, texts, still, and moving pictures have great potential to present complete schedule information without requiring the conventional schedule presentation methods. A proper combination of these can create an impressive presentation through the 4D CAD model.

## Conclusions

The 4D CAD model is a novel presentation

method of the construction plan. It shows a superior capability to the conventional schedule presentation methods, namely Gantt chart, the network diagram, and the calendar. It clarifies the construction sequence and the spatial constraints with an unambiguous visual perception. It results from the integration of design and planning data. Also, it conforms to the present trend of development that focuses on the parametric 3D design and drafting, the data integration of the whole project's life, and the building information model (BIM). The use of the 4D CAD model is anticipated to be widespread in the near future.

This paper addresses on the presentation deficiencies of the existing 4D CAD model. It proposes some enhancements for this method. These proposed enhancements draw on the advantage analysis of the conventional schedule presentation methods. The four aspects of the visualization were addressed, namely the overview of the schedule, the activity duration, relationship, and the project progress tracking. The prototype of the 4D CAD model was developed using AutoCAD and MS Project applications. The enhanced 4D visualization exhibits in the AutoCAD environment, while being supported with schedule information from MS Project. This integration was programmed with VBA code using the Automation and ActiveX object technology. The manipulation and control of visual properties of 3D CAD objects was also programmed with VBA code using Component Object Model (COM). This enhanced 4D CAD model is anticipated to fulfill its presentation ability so that it could finally become a standard method.

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