EXPERIENCES ON DEVELOPMENT OF A 4D PLANT CONSTRUCTION SIMULATION SYSTEM

Shang-Hsien Hsieh[1], Chuin-Shan Chen[2], Yuan-Fu Liao [3]
Cheng-Tao Yang [4], and I-Chen Wu[5]

ABSTRACT

This paper reports the experiences in developing a 4D plant construction simulation system, named Construction Director, in an ongoing collaborative project between the CTCI Corporation (CTCI) and National Taiwan University (NTU). The current focuses of the collaborative design are on the user-friendly interfaces and functionalities of the binding (or linking) tool for defining the relationships between the objects in the 3D model and the work items in the construction schedule. The synthesized data are then utilized for automatic animation and user-controlled display of the planned construction progression. Because CTCI employs mainly Intergraph solutions for 3D plant design, Construction Director is implemented on top of Intergraph SmartPlant Review (SPR), which not only supports visualization of the 3D plant model with some capabilities for 3D object manipulation and information query but also provides API (Application Programming Interface) for functionality extensions. In this paper, the design and implementation of Construction Director are discussed and a portion of a real plant construction example is used to demonstrate the applicability of the system.

KEY WORDS

4D CAD, Scheduling, Plant Construction, Construction Plan Simulation System

INTRODUCTION

In the past decade, the 4D CAD technology, which binds 3D models with their corresponding construction schedules in its simplest form, has emerged rapidly. This is mainly due to the increasing recognition from the construction industry on the benefits of using the 4D CAD applications for increased productivity, improved project coordination, and optimized on-site resources. The realization of 4D CAD technology is also greatly accelerated by availability

1 Professor, Department of Civil Engineering, National Taiwan University, Taipei 10617, Taiwan, TEL: +886-2-3366-4313, FAX: +886-2-2368-8213, shhsieh@ntu.edu.tw
2 Associate Professor, Department of Civil Engineering, National Taiwan University, Taipei 10617, Taiwan, TEL: +886-2-3366-4275, FAX: +886-2-2367-2558, dchen@ntu.edu.tw
3 Assistant Chief Engineer, CTCI Corporation, 11 Fl., CTCI Tower, 77, Sec. 2, Tun-Hwa South Road, Taipei 106, Taiwan, TEL: +886-2-27009659 Ext 1103, FAX: +886-2-27066982, y.f.liao@ctci.com.tw
4 Postdoctoral Research Assistant, Department of Civil Engineering, National Taiwan University, Taipei 10617, Taiwan, TEL: +886-2-3366-4352 Ext. 12, FAX: +886-2-2368-8213, ct.yang@caece.net
5 Ph.D. Candidate, Department of Civil Engineering, National Taiwan University, Taipei 10617, Taiwan, TEL: +886-2-3366-4352 Ext. 12, FAX: +886-2-2368-8213, kwu@caece.net

of powerful commercial 4D CAD tools, such as Bentley's Navigator [6], Intergraph's SmartPlant Review [7], BALFOUR's FourDscape [8], Common Point's Project 4D and ConstructSim,[9] (Sheppard, 2004). Moreover, many research efforts have been carried out to advance the 4D CAD technology from simple 4D animation of construction progression to interactive 4D simulation of alternative construction processes (e.g., McKinney et al., 1996), and even to nD CAD that integrates 4D models to project information in dimensions other than 3D space and time (e.g., Lee et al., 2003; Tanyer and Aouad, 2005).

The CTCI Corporation (CTCI) is one of the largest integrated engineering and construction firms in Taiwan. CTCI not only has broad experiences in the planning, design, and construction of the refinery, petrochemical, general industrial, and power plants throughout the world, but is also active in the fields of environmental protection, energy, infrastructure, and transportation. Currently CTCI employs mainly Intergraph's Plant Design System (PDS) for 3D plant design and construction, and SmartPlant Review (SPR) for interactively reviewing and analyzing the 3D models of a plant. Although some 4D CAD simulation capabilities are supported by the ScheduleReview function of the Construction module offered by SPR as complementary software, CTCI still feels the need for a more user-friendly, flexible, and intelligent 4D CAD capability on top of the SPR in order to facilitate more efficient and effective 4D simulation and management of plant construction and to allow for better integration with CTCI's project resource management systems.

A two-year collaborative software development project between CTCI and the Computer-Aided Group in the Department of Civil Engineering at National Taiwan University was initiated in April 2005 for development of a 4D CAD system to better satisfy CTCI's needs. The focuses of the first year's development are two-folds. The first one is the development of a binding (or linking) tool that provides user-friendly interfaces and flexible object management and binding functionalities to ease the task of binding the objects in the 3D model with the activities (or work items) in the construction schedule. The second focus is on the development of a visualization tool that takes full advantage of the existing 3D capabilities of SPR for automatic animation and interactive simulation of the construction plan. The focuses of the second year's development are also two-folds. The first one is on the capability of linking the objects in the 3D model to related project documents and resource information, e.g., construction specifications, labors, and materials. The second one is the capability for simulating planned erection activities.

At this time of writing (February 2006), the targeted development of the 4D CAD system for the first year of the project has almost been completed and the system is named Construction Director. Therefore, the rest of this paper discusses the experiences in the analysis, design, and implementation of Construction Director. In addition, the major interfaces and functionalities of Construction Director are illustrated using a portion of a real plant construction example.

6 More information can be found at http://www.bentley.com/
7 More information can be found at http://ppm.intergraph.com/visualization/
8 More information can be found at http://www.BAL4.com/
9 More information can be found at http://www.commonpointinc.com/

SYSTEM REQUIREMENT ANALYSIS

Major system requirements for the targeted 4D CAD system, i.e., Construction Director, were identified at the early stage of the software development. The following summarizes the major system requirements. We remark that thanks to a light-weighted incremental and iterative software development process adopted herein, these requirements have been continuously refined and revised to meet the needs of users.

(1) The system should take full advantage of SPR's capabilities in manipulation and visualization of the 3D objects from PDS.

(2) The system should provide user-friendly interfaces for the construction planning engineer to bind the 3D construction objects with the work items in the construction schedule. Because the plant design tasks performed in PDS are typically divided among different engineering fields, e.g., structural engineering, piping engineering, etc., the grouping of the 3D objects resulted from the design process are quite different from that needed for construction planning in which the construction activities usually play the major roles in grouping the 3D objects. Therefore, the system should provide multi-purposed object search and grouping tools for the construction planning engineer to flexibly re-group the 3D objects from the design phase. For example, the engineer can search 3D objects with combination of specified attribute values across various design files then group these results in a user-friendly manner.

(3) The system should be able to import the construction schedule information from either Microsoft Project or Primavera Project Planner (P3), or both. It should also provide some editing capabilities on renaming, adding, and deleting the schedule items as well as modifying the attributes of schedule items. Two types of schedule items are needed: activities and work items. An activity is a top-level entity for grouping work items. Both the activity and work item may contain one or more work items. Only the work items are linked to the 3D construction objects. The hierarchy of the activities and work items may be displayed and managed using a tree structure.

(4) The system should support both automatic animation and user-controlled display of construction progression within a user-specified period of time. In the animation, the 3D objects are colored according to their different construction statuses.

SYSTEM DESIGN AND IMPLEMENTATION

Object-oriented technology is employed for development of Construction Director. The design of Construction Director takes advantage of several design patterns (Gamma, 1998) to achieve good maintainability and reusability of the system. Figure 1 depicts the basic framework of the system design. The framework consists of two major parts: the KernelFacade (Gamma, 1998) and GUI (Graphic User Interface) subsystems. The KernelFacade subsystem defines a higher-level and unified interface to the C-Style SPR API. It also enhances SPR's searching capability (Search Engine) and drives SPR's visualization engine for simulation of construction process (Animation Engine). The GUI subsystem consists of the Schedule Tree and Models List components. The Schedule Tree component uses a directory tree like interface to manage the hierarchy and attributes of the activities and work items for a construction schedule, while the Models List component uses a combination of folder-like and list-like interfaces for managing 3D construction objects.

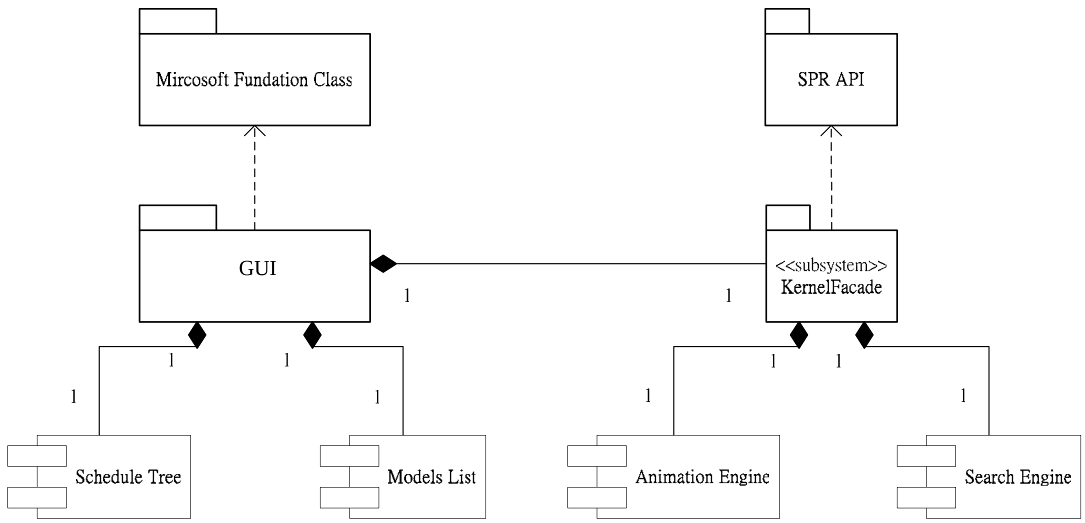

Figure 1: Design of Construction Director

The implementation of Construction Director is carried out in the Microsoft .NET (MS.NET) environment. Although SPR API supports both the Visual Basic and C/C++ programming, the C++ programming language is selected in this work because it supports object-oriented programming more powerfully and efficiently. In addition, MFC (Microsoft Foundation Class Library) is employed for implementation of the graphical user interfaces of Construction Director.

SYSTEM DEMONSTRATION

Figure 2 shows the user interface of Construction Director. The left-hand side window is used to manage the activity tree of a construction schedule, while the right-hand side window is used to manage grouping of 3D construction objects. A 3D model of a chemical plant (as shown in Figure 3) is used as an example to test and demonstrate the system. The 3D model is an integration of the designs from several different engineering divisions at CTCI. It consists of more than twenty-three thousand objects in more than twelve DGN or PRP files (i.e., PDS's design files). Therefore, it is not an easy task for the construction planning engineer to re-group the 3D objects and bind them with the corresponding work items in the construction schedule. This section demonstrates the functionalities designed in Construction Director for facilitating the construction planning engineer's tasks.

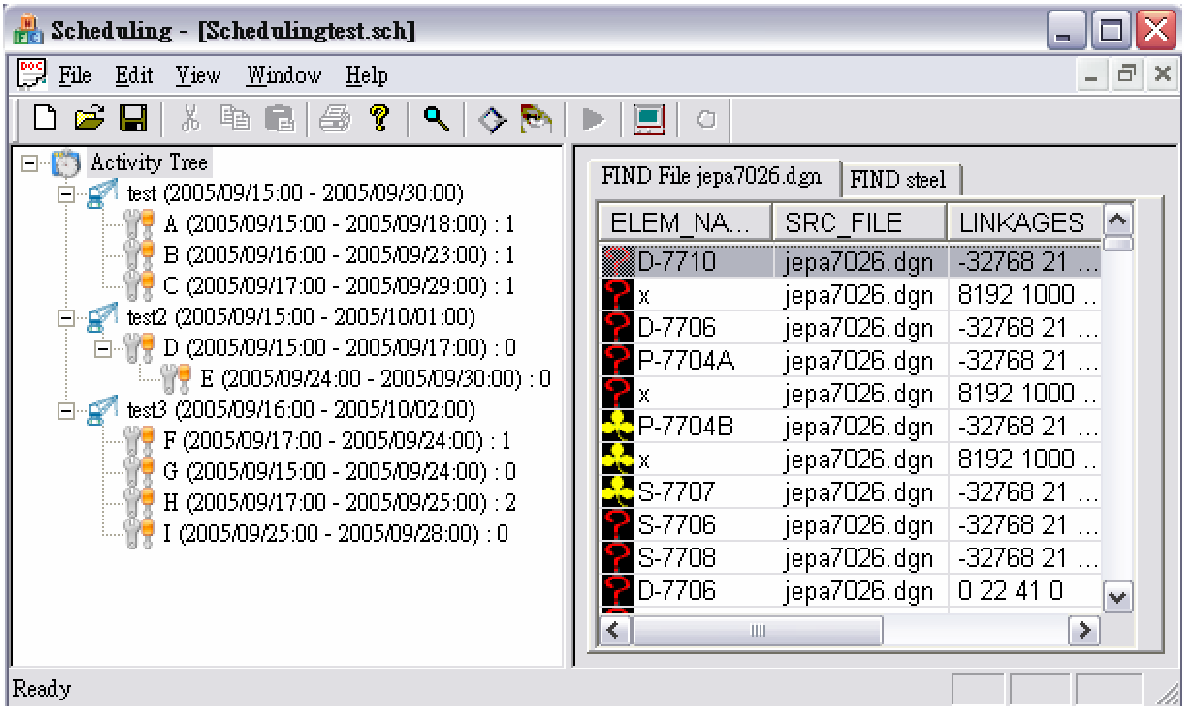

Figure 2: The User Interface of Construction Director

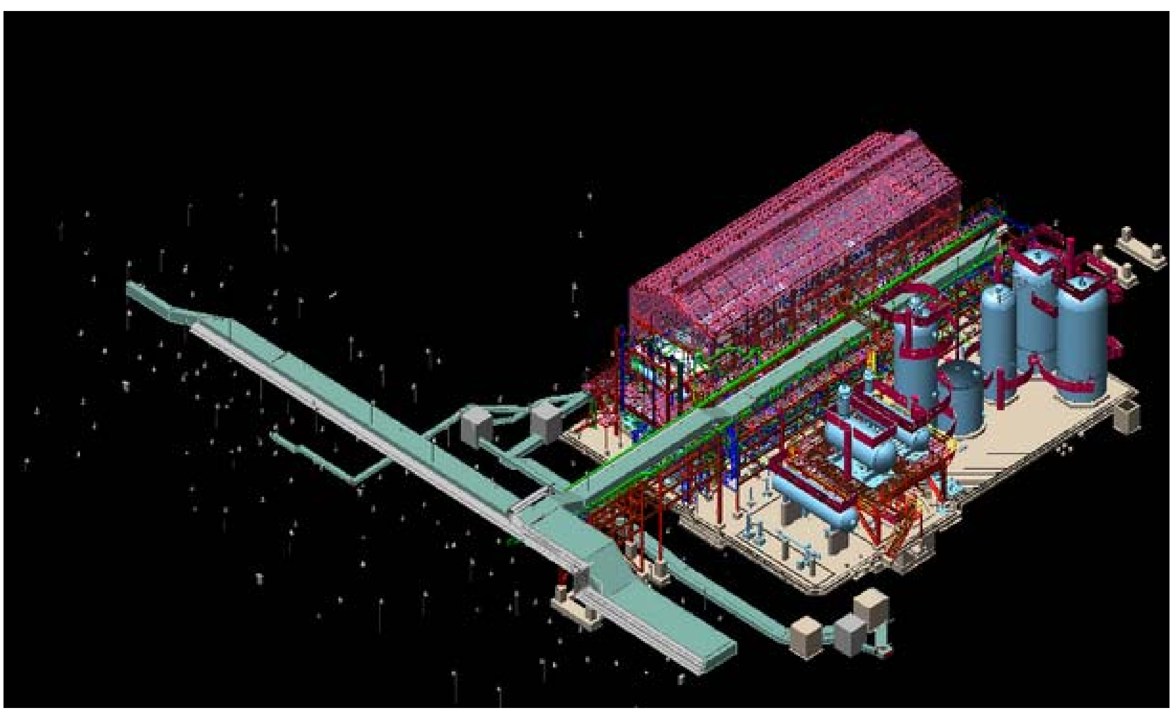

Figure 3: Display of the 3D Model of an Example Chemical Plant Using SPR

Figure 4 shows the search capability of Construction Director. A dialog window is designed for the user to search a group of 3D objects using a combination of search criteria, such as objects in specific DGN files, objects with a specific attribute (or label) value, and objects with specific keywords. The objects resulted from each search are organized into a new group with a user-defined name (as one of the folders shown in the right-hand side window of Figure 4). The user is also allowed to select (or hit-test) a 3D object directly from the SPR display window (e.g., Figure 3) and then to add it into an object group. In addition the user can highlight the entire group of 3D objects or only selected ones in the SPR display window.

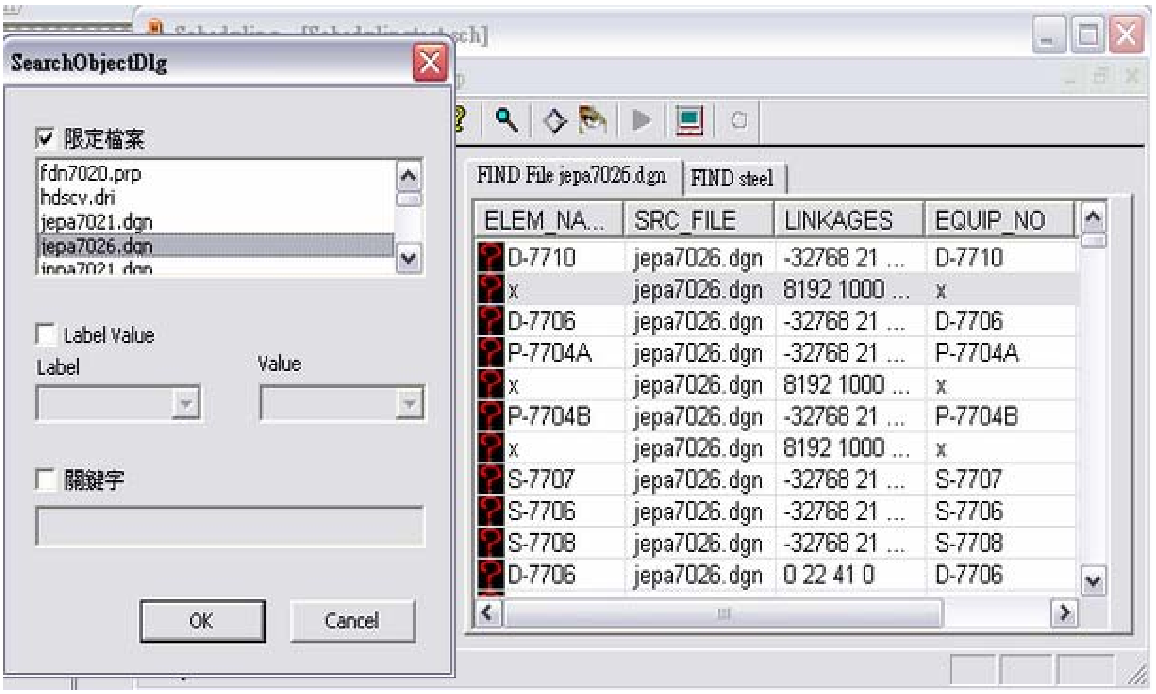

Figure 4: Objects Searching in Construction Director

For managing the activity tree and its work items, the user can easily adjust the relationships among activities and work items through the drag & drop operations. If the user double-clicks on an activity or work item, a dialog box is popped up for the user to edit the attributes of the activity or work item.

For binding together the 3D objects and the work items, the user can simply drag & drop a selected 3D object to the target work item. Even if the work item does not yet exist in the activity tree, the user can still drag & drop the 3D object to the target activity and the system would automatically create a new work item under the activity. This feature is particularly helpful when the user wants to drag & drop a group of 3D objects to the target activity for the reason of simplicity and efficiency. In addition, two different kinds of symbols are employed to indicate if a 3D object has been assigned to a work item (see Figure 2 for the symbols in the ELEM_NAME column).

After the binding is completed, Construction Director can be used to animate the construction progression for a given time interval, as shown in Figure 6. During the animation, the 3D objects in the plant model are highlighted in different colors depending on their construction statuses. Table 1 shows the color scheme implemented in this work.

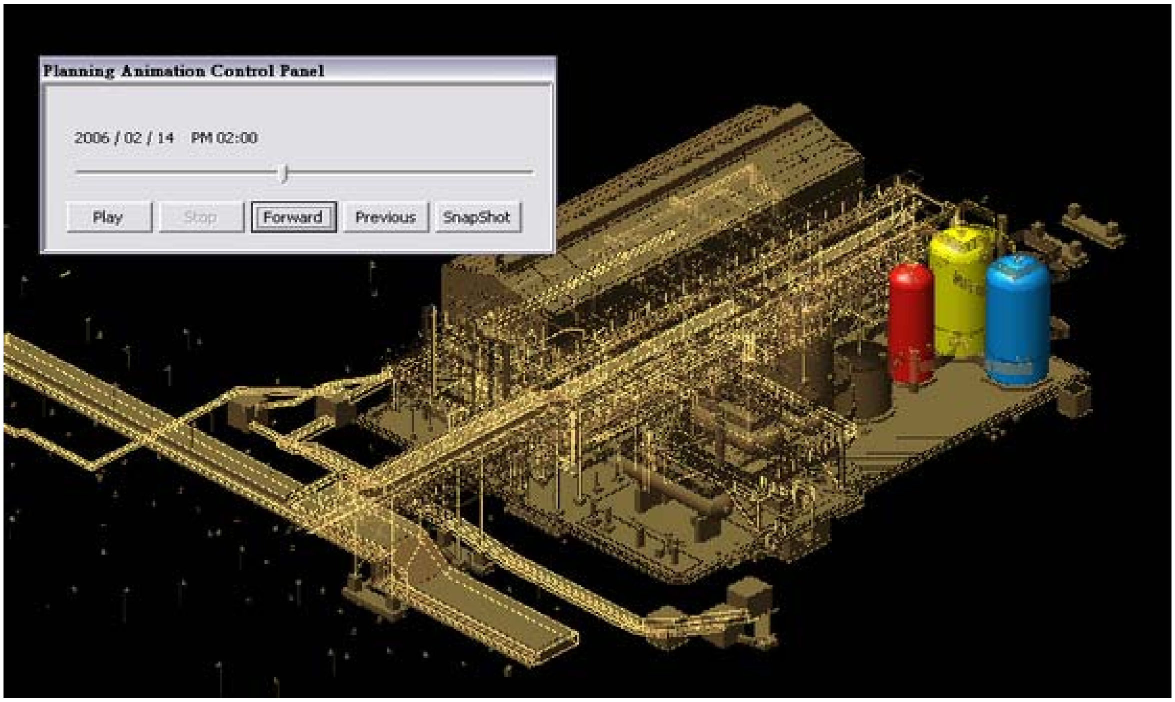

Figure 6 Display of Construciton Status of 3D objects using varied colors

Table 1: Color Schemes for Illustrating Different Construction Statuses

Color	**Construction Status**
Pink	The construction had been completed before the given time interval
Red	It is currently under construction
Yellow	The construction has been just completed
Blue	The construction has been completed within the given time interval
Orange	The construction has not been started yet

CLOSURE

In this paper, discussions have been given on the development of Construction Director, a 4D plant construction simulation system, in an ongoing collaborative project. It is felt that most of the major system requirements obtained in this work are also essential requirements for development of practical 4D CAD systems. The object-oriented design of the system takes advantage of the capabilities provided by SPR to minimize the development effort. As already demonstrated in the paper, the current system has implemented several good tools and interfaces to facilitate 4D construction simulation. It is hoped that further evaluation on the design and implementation of the system can be obtained through practical application of the system at CTCI in the near future.

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