Interactive 4D-CAD

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ABSTRACT

While 4D models (3D plus time) are becoming more prevalent in design and construction, the characteristics and use of these tools is still being explored. Research at CIFE(Center for Integrated Facility Engineering) is focusing on the usability of the models - not only in terms of their visual and communicative impact - but impact on the construction design process. We are developing a 4D-CAD tool which enables construction designers to easily build and interact with a 4D model. The goal is to improve the decision power of 4D models by facilitating rapid prototyping and analysis of alternative schedule proposals.

1.0 Introduction

Current techniques used to manage the design, planning and construction processes of a facility employ software tools that abstract the processes and reduce a complex building cycle to a Gantt chart or CPM schedule. This abstraction represents a best effort to communicate a progression of linked activities over time. The hurdles of transforming two-dimensional drawings to reality are cleared by a separate exercise featuring scale models and successive levels of detailed drawings.

A strong need still exists for a comprehensive tool which allows architects, engineers and contractors to simulate and visualize construction sequences as part of an interactive experience. The 4D model provides the basis for a common language between all parties and a representation of the schedule itself. Design and construction planning alternatives can be assessed realistically within the context of space and time. Simultaneously modeling both the temporal and spatial aspects of construction intent can optimize and justify the decisions involved in the planning and design of projects.

2.0 What is a 4D-CAD Tool?

Conceptually 4D-CAD is a medium representing time and space— a type of graphic simulation of a process. In construction, a *4D animation* simulates the process of transforming space over time and reflects the four-dimensional nature of engineering

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and construction. Producing a 4D animation involves linking a 3D graphic model and a construction schedule through a third-party technology (Figure 1). This linking process yields a *4D model* which represents the product model (the design of the facility) and graphically incorporates the information traditionally represented in the construction schedule. By communicating the schedule as objects within the graphical model, the temporal and physical aspects of the project are inextricably linked, as they are during the actual construction process.

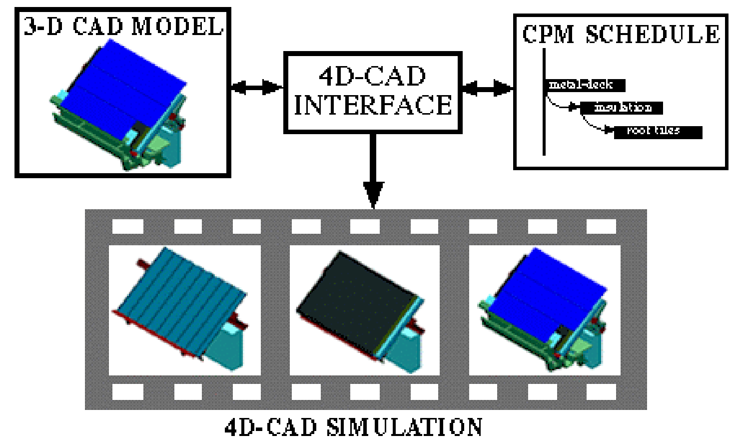


Figure 1: Components of 4D-CAD medium

A *4D-CAD tool* supports the process of capturing and dynamically managing the interaction between project components and resources over time and supports real-time interaction of users with the 4D-Model. This tool also encourages the communication, approval and improvement of construction schedules by various parties, such as construction managers, clients, designers, subcontractors and community members. Thus far, two distinct generations of 4D CAD have been defined - Visual 4D-CAD and Collaborative 4D-CAD. The first generation(Visual 4D-CAD) encouraged further exploration and helped to formulate objectives of the current Collaborative 4D-CAD effort.

3.0 What is the Need for a 4D-CAD Tool?

Representing the relationship between time and space provides a powerful mechanism to visualize and communicate design intent. A 4D-CAD tool can help address common problems in today's construction design process, such as:

1) ***Inability to identify construction problems prior to construction***
During one project coordination meeting for a roofing installation, the General Contractor and the sheet metal, roofing and stucco subcontractors discovered that the roof edge detail, as designed, required a change in design and the construction sequence. The 4D CAD tool prompts team members to question design intent, analyze the construction sequence, and implement changes which improve productivity and field coordination.

2) ***Lack of information for construction planning***
Traditional 2D documentation provides no information about sequencing of activities and installation schedules for specific design elements. Construction schedules rarely provide the additional detail necessary for construction personnel to orchestrate the actual field installation of design components. As a

result, bidding procedures rely upon the experience of contractors to account for factors beyond the design information. The 4D-CAD tool simulates the construction process, and encourages pre-planning at the early stages when optimal solutions can be planned and implemented.

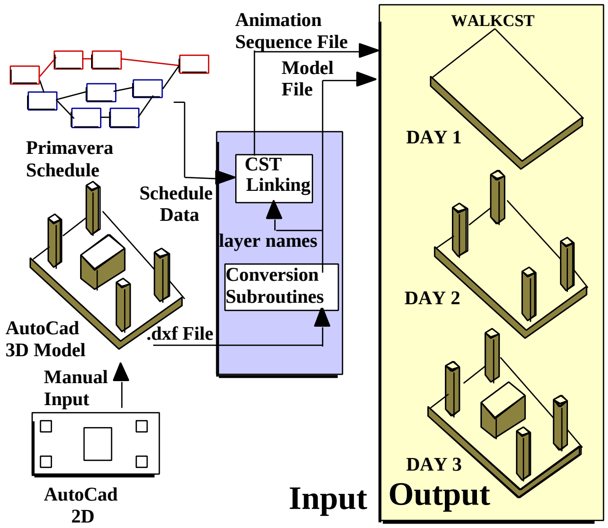
3) ***Clients cannot interpret project documentation***
In the case study implemented during the Visual 4D-CAD project (San Mateo County Health Center), available design documentation was inadequate in communicating the proposed construction process to the client. The remodeling and renovation project included construction of five new buildings, demolition of three existing buildings, and renovation of the existing main hospital. Due to the complex, multi-phased nature of the project, a clear visual representation was required to ensure that issues such as traffic patterns, containment of disruptive operations and overall coordination were completely resolved. The Visual 4D-CAD model was instrumental in assuring the client that the construction work would not interrupt daily hospital operations.

At the Center for Integrated Facility Engineering (CIFE), we are working to see how 4D-CAD tools can support and address problems such as these. The goal is to support the interactive exploration of design and construction alternatives, facilitate the decision-making process, and enhance the nature of collaboration between project team members.

4.0 First Generation 4D-CAD: Visual 4D-CAD

Visual 4D-CAD utilized existing 4D-CAD tools to model over 30,000 3D elements of the proposed San Mateo County Health Center campus expansion. The San Mateo project is a multi-phased project presently underway and scheduled for final completion in 1999. It involves over 280,000 square feet of new building floor area and over 40,000 square feet of remodeled space. 3D modeling was done with AutoCAD and animation was done using a Silicon Graphics Indigo Elan. Jacobus Technology provided assistance in the form of Bechtel's Walkthru® software and Construction Simulation Toolkit®, which allowed the 'batch mode' linking of the existing schedule to the San Mateo 3D models (See Figure 2) and produced a 4D animation(Collier & Fischer, 1995).

FIGURE 2: 4D-Modeling process for Visual 4D-CAD



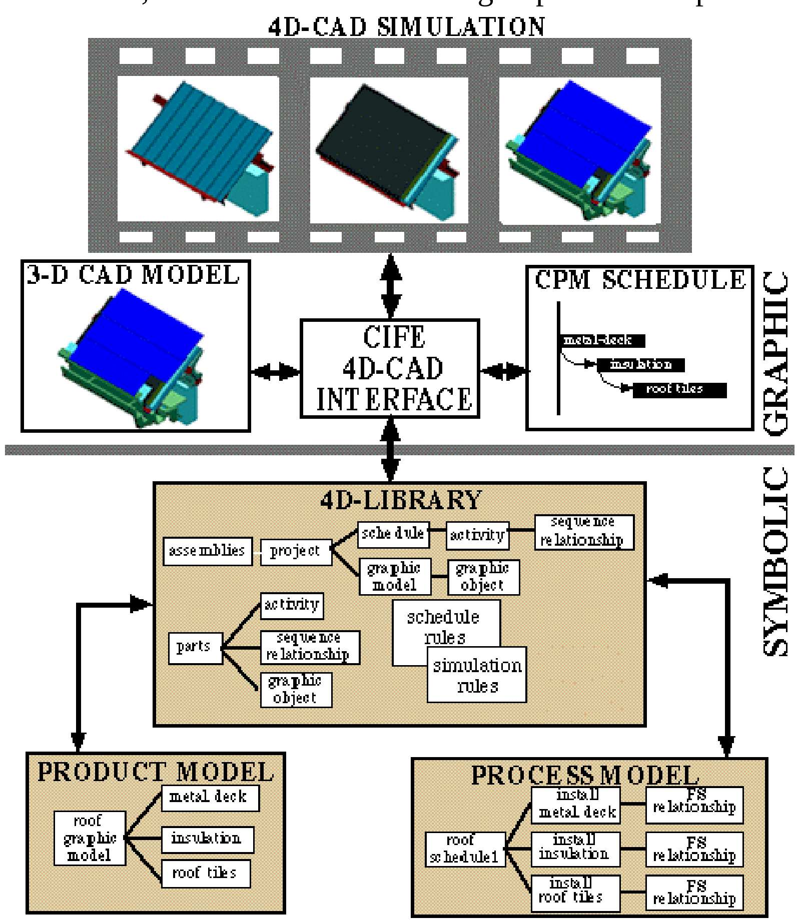
Since the health facility is the only major hospital in San Mateo, it was imperative that hospital operations continue uninterrupted during the construction period. The creation of a 4D animation met these complex needs for detailed coordination of activities, minimized planning errors for both the owner and construction personnel, and demonstrated the ability of the 4D-CAD medium to improve the construction process. Visualization of the proposed construction activities encouraged evaluation and input by more informed project team members. Those involved included the designers, subcontractors and other construction personnel, external parties and owner representatives.

The San Mateo project also elucidated several important points about the limitations of the Visual 4D-CAD tool. One restriction to the use of the tool is the initial need for a complete 3D model, whose creation from 2D drawings requires a large investment of time and effort. Secondly, the graphical and schedule information was integrated from different applications, preventing the user from interactively composing the schedule and benefiting from the knowledge gained during the process. Finally, implementing local changes to the CAD model or schedule required that the user re-link all activities to their corresponding CAD elements.

5.0 Current Generation: Collaborative 4D-CAD

Visual 4D-CAD produces a 4D animation for designers to evaluate and review the schedule they propose. The process of creating this 4D animation, though, does not affect traditional scheduling processes since it merely links the 3D-model and an existing schedule. While Visual 4D-CAD proved to be visually powerful, it did not address how the schedule was developed. The main objective of the current generation 4D-CAD work, entitled "Collaborative 4D-CAD", is to improve the interaction between the scheduler/designer and to improve the process of creating a 4D animation. Until we develop an easy way to create 4D animations, we are limiting the power of the tool to affect and improve the construction design process.

Limiting the ability to create these animations is the separation of the underlying information, namely the graphic information in AutoCAD and the schedule information within Primavera. Simply linking the two technologically does not affect the process of creating relationships between time and space. Visual 4D-CAD merely reflects those relationships. The 3D-graphic model and the schedule information must be represented both graphically and symbolically, in product and process models respectively, to create a *4D model.* Thus a 4D-CAD system not only produces an animation, but a 4D model consisting of product and process



information, which can easily be updated and altered to create alternative 4D simulations.

Our approach to developing this 4D-CAD system was influenced by two different concepts: 'interpretation' and 'user's conceptual model'. Previous work at CIFE (Semantic Modeling Extension (Clayton, et al., 1994)) linked a 3D graphic model in AutoCAD to an object-oriented knowledge system, Kappa®. The central concept of SME is "interpretation", the process of selecting a graphic object and classifying the object with specific characteristics. Similarly, we envisioned users simply selecting graphic components of a 3D model, such as a beam and then associating the beam with a schedule activity and defining its sequential relationships.

The second concept 'user's conceptual model' (Norman, 1988, Smith, et. al, 1982) describes how users form a mental model of the work they are trying to perform. In this case, the user is a scheduler familiar with traditional scheduling methods but not with creating and relating a schedule associated with a proposed 3D graphic model. Since this process is new to a scheduler we developed the functionality of the 4D tool around expected user behaviors and functions the user would want or need to build a 4D model. For example, a user may want to create activities and then associate them with parts of the graphic model. Another user may want to select graphic components and then associate them with activities. Both processes are available for the user in *CIFE 4D-CAD.*

Implementing these concepts in the CIFE 4D-CAD prototype involved working with two environments - AutoCAD® representing the user interface and graphic product model and Design Power's Design++® (D++) representing the symbolic product and process models. D++ is a knowledge-based engineering design system that provides object-oriented representation and model-based reasoning with tight links to

Figure 3: Relationships between CIFE 4D-CAD system components

AutoCAD. Figure 3 shows the relationships between the core components of the system and Figure 4 shows screen snapshots of the implemented components:

1) 4D-Library and Rules

A library contains parts of the symbolic model which make up the product and process model such as 'graphic_object' representing a graphic component in the 3D-model or 'activity' and 'link' representing schedule activities and their sequence relationships. Rules define relationships and attributes of specific parts within the model.

2) 4D-Model

The model consists of instantiations of the product and process model. For a specific project, such as the gutter, the product model represents parts of the gutter 3D-model and the process model represents the construction activities needed to build the gutter.

3) 4D-Interface

Through the 4D interface users can manipulate the D++ 4D-CAD Model to create activities, grab representations of 3D objects, relate those objects to activities, and invoke animation of all or part of the schedule. The 4D-CAD pop up menu lists all of the functions the user needs to build a 4D model and perform a simulation. The user never has to see or work with the symbolic model in D++.

As an example of how the system works, a user starts with a 3D roof model consisting of roof components such as metal deck and tiles. To begin building a 4D schedule the user can select ‘Add Graphic’ from the 4D pull down menu and select an AutoCAD object(s) representing ‘Metal deck.’ Concurrently in D++ a component ‘graphic_object’ is created and related to the AutoCAD component. The user then associates the ‘metal deck’ graphic object with an activity (i.e. the user creates an activity ‘install metal deck’) and provides a duration and a predecessor/successor

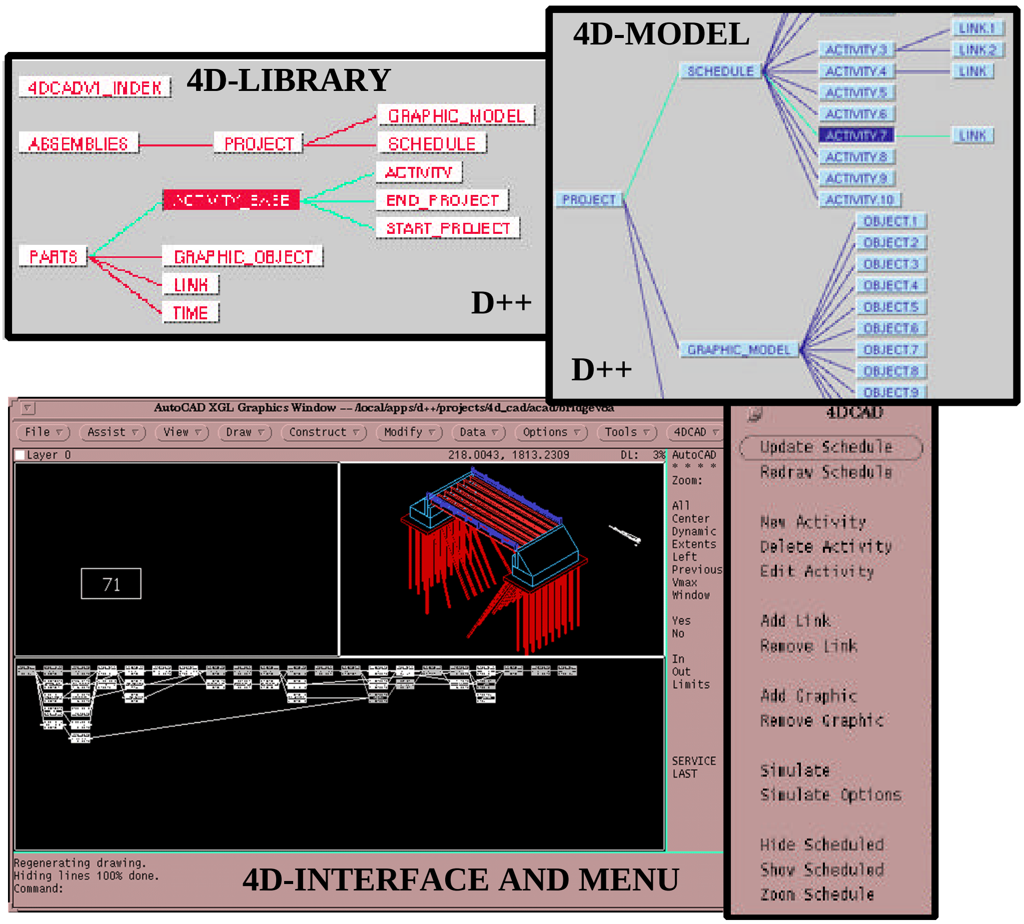


Figure 4: Implemented CIFE 4D-CAD components

activity.) Again, a symbolic component —'activity'— is created and a 'link' to represent the activity and its 'link' to a predecessor/successor. The user then adds an 'insulation' graphic object and activity and so on. At any time the user can see how the pieces are put together by running a simulation. If something does not look right, the user can remove relationships and/or activities and associated graphic objects. The user now has the ability to try out a number of alternatives and quickly visualize the affects of his/her construction planning changes.

6.0 Defining The Characteristics Of 4D-Modeling Systems

Part of the process of building this system is developing the specifications and expected functionality of a 4D-CAD system. During the 'Collaborative 4D-CAD' project we realized that 4D-CAD is not just a visual medium, but can be defined characteristically across three dimensions: visual, knowledge, and interaction. To date, we have begun to advance the system within each of these dimensions and are beginning to explore future improvements. We now discuss CIFE 4D-CAD with respect to each of these dimensions and the issues we have explored and will explore.

The visual dimension extends from 2D graphic representation to a virtual reality experience of information. 4D-CAD lies in-between these two extremes with the added dimensions of 3D and time. Our objectives at CIFE are not to build a 4D-CAD VR tool, rather a tool which simulates the construction process enabling users to visualize the construction process. Within the visual dimension, issues related to the level of abstraction of the 3D-model must also be explored. One issue we will look at is how to manage the various levels of detail in a construction schedule from the master schedule to a detailed subcontractor schedule. With 4D-CAD we can visualize each of these as well as the relationship between them.

The knowledge dimension moves from manual proposal, interpretation, and evaluation of a design towards fully automated generation of a schedule from a 3D-graphic model (Fischer, et al., 1995). The scope of the current project does not include any sort of automation. We have begun the process of interpreting 3D graphic models but will need to include more classification of objects and relationships between them before automation of the scheduling process is possible. In the future we plan to have a tool which includes both manual and automated scheduling.

The interaction dimension moves from a state where one person interacts with the design to a point where several people interact with each other and the design. The goal of "Collaborative 4D-CAD" is to establish a 'common ground' on which all designers can interact and enable them to better understand the design intent. To date our focus has been on a single user interacting with a 4D-Model and multiple-users viewing 4D-animations. Future improvements will consider how a 4D-Model is built with input from several people/subcontractors and how evaluation for multiple perspectives can take place across a network. By improving the level and quality of the interactions users can focus more on the goals and objectives of the project.

7.0 Conclusions

4D-CAD is evolving in both form and function. Our 4D tool—CIFE 4D-CAD—produces 4D simulates and models in both symbolic and graphic form. Product and process information are related within the 4D model and the 4d animation. Furthermore, the function of the CIFE 4D-CAD tool is to *produce interactive 4D models*. for 4D animations. This tool empowers construction designers to build a schedule directly related to a 3D-model of a facility and to understand the relationships he/she develops. We envision this tool not as a 'tester' of an existing schedule proposal but as a 'decision' tool which supports both the process of building the schedule as well as the evaluation of its viability.

8.0 Acknowledgments

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