Four-Dimensional Computer-Aided Drafting – Current Status and Potential Business Applications

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ABSTRACT

Time and money can easily be lost through poor project planning and scheduling of on-site labor, materials, and equipment. A lack of coordination in ensuring that materials and equipment are delivered to the site on time can be devastating to the project, resulting in delays and lost productivity. This paper addresses current scheduling practices, the future of scheduling, as pertaining to 4D CAD, and most importantly, what problems management must overcome to utilize this new technology.

INTRODUCTION

The combination of the graphic potential of 3D CAD with the construction project schedule is known as 4D CAD. In the past few years, information technology (IT) advancements have emerged from research, development, and conceptualization to commercial markets where they are now available for implementation (Koo and Fischer, 2000, Christodoulou, 2002). Hardware and software applications are available today that can be practically used for the increased efficiency of construction work processes. Although some of these tools are in their technological infancy and have been utilized only by early adopters, others have been around long enough to see widespread adoption outside the construction industry (Hannon, 2007).

The construction schedule communicates the general contractor's planned means and methods and the planned sequence and timing of the contract work (Songer, et al, 2003). Without a schedule, the trades performing the work or the vendors supplying equipment and materials to the project will not know when their work needs to be performed or how their work relates to other work on the site. The general contractor's construction schedule also communicates the plan to the designer and owner (Webb, et al, 2004). The construction schedule normally provides the project team with a plan for completing the overall project on time and within budget.

Without a good schedule there is no way that the project manager can communicate the plan to other project participants, establish production goals, monitor and measure project progress, or manage change. Construction planning and scheduling is a tool that enables the project manager to manage and measure time, resources, quality, and risk (Akinci, et al, 2002). Good scheduling can eliminate problems due to production bottlenecks, facilitate the timely

procurement of necessary materials, and otherwise ensure the completion of a project as soon as possible. A deficient schedule can result in poor management of laborers and equipment which in-turn will delay the completion of critical activities. Not only will the critical activity be delayed but also all successor activities. Realistic and regularly updated schedules help you finish on time, within budget, and prevent claim litigation.

This paper will focus on the evolution of construction as pertaining to 4D CAD scheduling. It will cover the weaknesses and/or limitations of traditional scheduling techniques (i.e. 2D PERT and Ghantt Charts) as well as both the advantages and disadvantages of 4D scheduling. It will outline what universities are leading the pack in the development of 4D CAD/4D scheduling, what software are currently available, and give examples of case studies where 4D technology was utilized. Lastly we will look into the future of 4D scheduling to determine what skills will be required for successful use of 4D scheduling

TRADITIONAL SCHEDULING SOFTWARE

- Suretrack
    - SureTrak can be used for planning, scheduling, and managing projects. It can also be used to develop a timetable for a project, to predict the effects that schedule changes will have on the future of the project, and to forecast resource requirements. SureTrak offers presentation-quality graphics that show schedule (dates) and resource information, separately or combined, in great detail or summarized for management presentations.
- Primavera Project (P3)
    - Primavera Project Planner (P3) gives project managers and schedulers control. Due to its ability to handle large-scale, highly sophisticated and multifaceted projects it has become the clear choice for many project professionals. P3 allows an unlimited amount of resources and target plans for up to 100,000 activities. It also provides the user a multitude of ways to organize, filter and sort activities, projects, and resources.
- Virtual Boss
    - Virtual Boss is geared towards the inexperienced computer user. Its simplicity makes it easy to get started with little or no training involved. It is a no strings attached software capable of scheduling and task management.
- Microsoft Project
    - Microsoft project is the most popular software. It is used to track resources and maintain project schedules by storing the information that is entered and calculating it much like an excel spreadsheet. It builds on itself, meaning the more information that is provided, the more accurate it becomes.
- AEC FastTrack 8
    - With Fast Track you can outline multiple projects, assign resources, track cash flows, set up task dependencies, and add colorful legends and graphics. You can also display project information as a Gantt chart, a traditional calendar, or a resource graph that tracks people, equipment, and materials essential to the project success.
- Kick Start

- This is the fastest, easiest way to plan and schedule projects. Its focus is both on planning a project strategy and building a project schedule. Project Kick Start's 8-step planning icons focus your attention on the structure of your project—goals, resources, obstacles, and other strategic issues critical to your project's success.

DISADVANTAGES OF TRADITIONAL SCHEDULING TECHNIQUES

Traditional design and construction planning tools, such as 2D drawings and network diagrams, do not support the timely and integrated decision making necessary to move projects forward quickly. They are not capable of providing the visual integration technology that is needed to quickly and efficiently modify and adapt the design of a complex multi-engineered building.

Manual manipulation of 2D construction schedules is an arduous task with mounds of paper being transferred between engineer, architect, owner, and general contractor. Furthermore, the ability to overlay and coordinate the mechanical, electrical, and plumbing systems in confined spaces, such as above ceiling in corridors requires numerous drawings and hours of coordination meetings.

The origination of problems in the project planning phase of construction usually stems from an individual's misconception of reality, particularly in the case of multi-storey buildings. One must have a good sense of 3D construction in order to prepare and successfully plan for the work processes that lay ahead. The modeling and virtual simulations that 4D CAD allows decreases the chance of misconception and quickens the workflow processes. This is one way to decrease the duration of the projects and at the same time keep the schedule as realistic as possible.

This kind of a schedule is not a particularly good communication means for individuals who have different backgrounds and may not necessarily be familiar with formal scheduling outputs. Building trust between project parties and giving the owners and users an opportunity to analyze and give feedback of the construction process plans is essential.

DESCRIPTION OF 4D CAD/4D SCHEDULING

4D CAD SYSTEM has made it possible to simulate such situations visually even from the planning phase. There are two technologies within the 4D CAD SYSTEM, one is "Construction Method Simulation" using 3D CAD model data, and the other is "Schedule Visual Simulation" that has been built by combining the schedule data from the general schedule network tool and the 3D CAD model data. With these simulations, the 4D CAD SYSTEM enables the construction engineer to support the construction plan while monitoring and understanding the site scenes on his PC at all times. (JGC Corp. 1996)

4D CAD combines a virtual three dimensional computer-aided design and adds the fourth dimension which is time. 4D CAD is a kind of information visualization that is easier to understand than traditional methods, such as 2D drawings and time schedules, which are currently used to manage construction projects. With the help of 4D visualization, it is easier to align the product (the building) with consumer needs.

ADVANTAGES OF 4D CAD/4D SCHEDULING

The benefits of employing 4D CAD scheduling are clear.

- Material Fabrication and Procurement

The process of developing 3D and 4D models, with early involvement of collaborative project stakeholder teams, lends itself well to projects with fabrication-intensive materials and equipment requirements. The emergent philosophy of Lean Construction encourages the use of 3D modeling with emphasis on reducing lead time for engineered-to-order products, incorporation of cost modeling, integrating product and process design, and supply-chain management (*LCI Research* n.d.).

- Constructability Review

Construction project constructability reviews are "peer-review" sessions of a project's design intentions. Various project stakeholders review the design to add perspective on construction efficiency and effectiveness, suggest changes in relation to cost-effectiveness and assembly relationships, and value engineer major component parts of the design. 4D CAD is an effective tool for this purpose. Not only does it force the stakeholders to collaborate early in the manufacture of the required 3D model, but the visualization of the sequential building process illuminates material staging and fabrication issues, spatial requirements not easily detected without visualization, and reveals conflicts, errors, and inconsistencies in the planning stage. Detection of interferences during the design process provides opportunities for quality assurance in the construction phase (i.e., on site) (Gao et al. 2005).

- Communication of Building Methods and Systems

Case studies have proven 4D CAD models to be the most effective system to date that communicates the design intention to all project stakeholders. The ability to visualize sequential planned construction operations allows project participants to consider (experience) constructability issues that can only be imagined (from prior experience in similar situations) using 2D tools. Most case studies emphasize the benefit of spatial analysis regarding avoidance of trade stacking, equipment placement, material fabrication and staging, and site organization. The phenomenon has been referred to as execution space (Heesom and Mahdjoubi 2004). In applications to transportation facilities that are commonly constructed under traffic use, the project phasing can be designed while a series of scenarios are visually analyzed, because traffic count can be an included dataset of the 4D model. If sufficient detail is included in the model, the driver's perspective can be simulated or experienced through virtual reality (VR). This is an incredible design and planning advantage because planners can adjust roadway and bridge elevations for maximum driver safety. In addition, the visualization of the phasing from the

drivers perspective can aid planners in the design and placement of traffic control and maintenance devices, permanent and temporary signage, and other safety features. It has been proposed that database object libraries be created (standards) for use in 4D models specific to these highway and traffic elements (Liapi 2003).

- Quantity Tracking

When modelers develop 3D CAD models, they typically embed building objects with quantity data. When these objects are linked to construction activities in a schedule, quantity information is made available to the 4D model. When the quantity data contained in the 3D models is associated with construction activities in the 4D model, it is easy to produce quantity surveys of a facility's components. The 4D model allows comparison of as-designed, as-bid, and as-built material and component quantities. This fringe benefit of the modeling process, which is currently time intensive and costly, should be considered as "debit" cost, and subtracted from the normally time-intensive estimating process of the project delivery life cycle.

- As-Built Documentation

4D modeling allows the user to shift time in the proposed construction work plan either forward or backwards. This ability, given that the scope detail is sufficient and that the component quantity datasets are a part of the model, allows the potential of documenting as-built quantities by declaring the percent complete of either tasks (as is typically done in 2D schedules) or facility components. Fischer and Liston (2001) describe separate schedules and models for as-built, as-planned, as-revised, and as-proposed projects. With the ability to set a baseline construction work plan, users could track as-built quantity variance from as-designed and as-bid work plans. Smith (2001) discusses the potential of capturing as-built data in the model to serve for information and knowledge throughout the operations and maintenance stages of the facility life cycle.

- Public Relations

4D CAD has been widely reported to be a valuable tool in expressing design intentions and construction sequence plans to individuals not familiar with visualizing from 2D media. For construction agencies, the use of 4D CAD can effectively communicate the phasing or staging sequences of projects that are long in duration and complex in relation to 2D visualization.

In addition to the above benefits, the following are also potential benefits:

- The creation, analysis and optimization of schedules
- Design to build/build to design processes
- Risk reduction
- Reduction in subcontractor costs
- Management of contractual issues and claims
- Winning more business
- Shows the status of the model at anytime.
- Shorter estimating duration.

- Better documentation & reproducibility of the estimation process.
- Elimination of field interferences.
- Understand the relationship between construction activities and facility operation for retrofit projects,
- Understand and improve the use of work, access, and staging areas over time,
- Identify spatial conflicts among crews and other production elements,
- Analyze activity sequencing,
- Improve work flow for subcontractors, and
- Visualize the construction work to be done for a work zone, time period, or subcontractor

DISADVANTAGES OF 4D CAD/4D SCHEDULING

In the cases of processing plants, power plants, and offshore plants, which are much larger projects than the typical project, the design team will utilize 4D technology. The magnitude of the project almost requires the design and engineering teams to produce a 3D model. However, for the typical project the biggest obstacle to 4D CAD technology is the desire to minimize costs and stay within budget. The owner typically awards the contract to the lowest bidder and the general contractor then subcontracts each phase to the lowest bidding firm, and thus 4D designs is rarely desired.

According to Laurel Sheppard, "Another problem is that 3D models need to accommodate the 4D modeling process. 4D modeling requires significant project scope and schedule information, which might not be available. The better the schedule the easier it is to build a 4D model. The 3D models might be inconsistent in geometry or schedule data, lack data in some areas, be too data heavy in others, or lack enough detail. The geometry definition might conflict with the schedule, making it difficult to link the two. However, providing a software tool to map construction organization of the facility to design organization can avoid these problems."

One of the largest barriers to implementation (at least in the conventional AEC industry) is that 4DCAD technology requires engineering designs as 3D models, something currently uncommon. Costs and return on investment are always determining considerations when contemplating investment in technology, especially technology that disrupts status quo business processes. 4D modeling for the delivery of construction design information would absolutely disrupt the status quo of business processes. The costs for using it include software licensing and hardware purchases, service costs of outside consultants if used for model creation or assistance, training, and in-contract salary costs of the model-building collaboration teams required at the outset. The total project cost percentage normally expended in the design development stage will increase substantially when 3D and 4D models are central to the project's strategic planning. Currently, in this early-adoption stage of the technology's history, the significant costs enable only large projects to absorb them.

An estimation made by Sheppard concluded that 75 to 80 percent of a 4D model's cost involves creation of the underlying 3D model. If the design team utilizes 3D, the cost will ultimately become a project benefit. The costs to implement a 3D model on a large project might run as low as one-half a percent of the project budget. However, the return on investment could

be 100 times that initial investment in project savings. Participants need to clearly establish a 4D model's scope and purpose early in the process in order to acquire the level of detail that is needed to see the desired cost-benefit ratio.

AVAILABLE 4D CAD SOFTWARE

CINEMA 4D R8-Special VectorWorks Edition by Maxon

The cinema 4D R8-Special VectorWorks Edition package enables architects and other CAD users to produce superb, photorealisitc images and complete animations of their Vector Works creations, quickly and easily.

- www.mmhk.com/e/news/20030121-maxon.htm

XSCAD

Provide professional CAD design services to all sectors serving the built environment, including architects, building services contractors, consultant engineers, civil and structural engineers and consultants. Provides a range of 4D CAD modeling and CAD programs.

- www.xscad.com

The Visual Project Scheduler (VPS) –4D CAD Software

The Visual Project Scheduler is and intuitive visual 4D CAD based approach for developing a project schedule.

http://www.visual- engineering.com/VisualProjectSceduler.html

Mine 2-4D

Mine 2-4D is the premier mine planning and scheduling tool for the mining industry. This technology breaks new ground in providing mine operators with the information to producing economically viable and robust mining scenarios.

- www.mine24d.com/default_english.htm

SUCCESSFULLY IMPLEMENTED 4D CAD TOOLS

There are a few cases of successfully implementing 4D CAD tools in the real world of business. The name of the projects and their brief description are summarized below.

Holder Construction Co. 3333 Riverwood Parkway, Atlanta GA, 30339

Holder used 4D CAD to construct schedule simulation of the Fed Ex Express World Headquarters in Memphis, TN.

Donohoe Construction Co. 2101 Wisconsin Avenue Washington DC, 20007

For Donohoe 4D is a vital element in the success of scheduling high rise condominiums.

Turner Construction Co. 9190 Priority Way West Drive, Indianapolis, IN 46240

4D helped Turner construct Parkview Hospital on time and within budget.

Manhattan Construction Co. 26 Executive Park Dr. Atlanta GA, 30329

4D helped Manhattan in the complicated development of the Hartsfield – Jackson International Airport in Atlanta GA.

Granger Construction Co. 6267 Aurelius Road Lansing MI, 48911

4D technology maintained the cost structure for Granger while developing Michigan State Universities Animal Health Diagnostic Lab.

Kraft Construction Co. 40 Pineapple Ave Sarasota, FL 34236

With the help of using 4D, Kraft as able to complete this complex 24 story condominium the Cozumel in Collier Co., FL

MANAGERIAL IMPLICATIONS OF 4D CAD IT IN BUSINESS ORGANIZATIONS

As advancements continue, 4D CAD will eventually become the standard for all phases of facility design, engineering, and life-cycle engineering regarding operations, maintenance, and retrofit. With the exponential growth of electronic commerce and the desire for faster and more accurate material procurement, 4D modeling will expand to fulfill this need. The problems that will have to be overcome include the need for faster data transfer and the lack of a uniform model.

Shifting data between project players with an open and free platform will dramatically improve the construction life cycle. Model sharing will require a revolution in the mindset of professionals within the industry. However, it will create a more integrated institution with facilities being built seamlessly. The creation of 4D modeling will tie every entity involved in the construction process into a closely intertwined organization, sharing ideas and establishing a holistic environment.

CONCLUSION

The 4D tool combines data and workflow management and 3D and 2D design, integrated multidiscipline engineering tools in a single environment that does not rely on now-outmoded CAD packages. The tool requires the users to closely collaborate with their co-workers, intended users and all other non-directly related workers. This, to some degree, will help implement the concept of total quality management. It also allows the CAD tools to be incorporated into the framework of a typical ERP project.

In the near future, 4D CAD will be utilized by planners, designers, and engineers to visualize and analyze many aspects of a construction project (Sullivan, 2003). From the 3D design of a project to the sequence of construction to the relationships among schedule, cost and resource availability data, 4D CAD will take the industry to a higher level of efficiency. Computer-based intelligent design will increase communication, and ultimately increase profit.

REFERENCES

(Complete list of all references are available from the author)