INTO THE FOURTH DIMENSION

By integrating three-dimensional computer-aided design technology with cost and scheduling programs, a pharmaceutical plant project team traded small increases in design time for greater productivity during construction.

Sheryl Staub
Martin Fischer
Melody Spradlin

A team of contractors for a pharmaceutical plant used three-dimensional computer-aided design (3-D CAD) technology intimately linked to cost and scheduling models to streamline the design/build process—leading to fewer unanticipated problems during construction. Although the necessary software has existed for some time, the pilot plant for Sequus Pharmaceuticals, Menlo Park, California, was among the first projects on which multiple firms collaborated using an integrated suite of design and project management software.

All of the work for the most intensive and difficult construction period was coordinated and sequenced with a detailed CAD model that the team referred to as 4-D because it integrated 3-D technology with a fourth dimension—time—by linking the CAD to a scheduling program. The 4-D model showed each subcontractor what to do (and what not to do) on each day of construction. The results were impressive:

- The piping and mechanical subcontractors fabricated all the large and expensive ducts and pipes directly from the 3-D CAD model, and both reported far greater productivity and virtually no rework.
- There was only one contractor-initiated change order on the work that had been modeled in 3-D, an accomplishment almost unheard of for work of this complexity.
- Requests for information were reduced by 60 percent compared with a similar project designed and built by traditional means.

In 1997 Sequus management decided to expand the company by

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building a pilot plant in an unoccupied warehouse adjacent to their office building. The warehouse offered 20,000 sq ft (1,858 m^2) of space, including 3,440 sq ft (320 m^2) for offices, 3,100 sq ft (288 m^2) for manufacturing, 2,900 sq ft (269 m^2) for process development, and 4,800 sq ft (446 m^2) for future expansion.

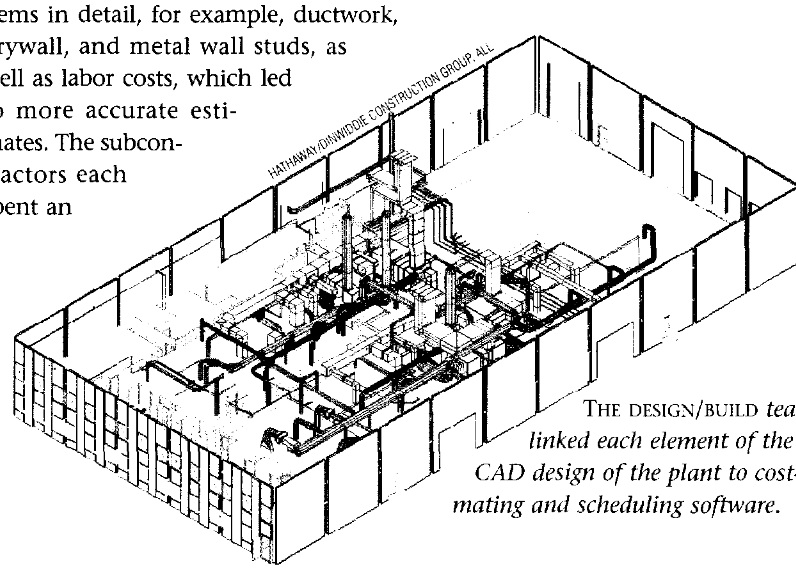
Sequus Pharmaceuticals selected an integrated design-cost-schedule approach because the method offered a rapid exploration of alternatives that could save time and money. Sequus executives felt that the detailed 3-D CAD models developed would also lower construction costs by helping subcontractors avoid sequencing conflicts during construction. Also, the company planned to use the 3-D CAD models after construction for validation, maintenance, operation, and budgeting for future remodeling or expansion projects.

The general contractor on the Menlo Park project, the Hathaway/Dinwiddie Construction Group, San Francisco, selected the members of the design/build team on the basis of their experience with 3-D CAD. The California-based project team comprised design firm Flad & Associates, San Francisco; piping subcontractor Rountree Plumbing, Redwood City; heating, ventilation, and air-conditioning (HVAC) subcontractor Paragon Mechanical, Santa Clara; and electrical subcontractor Rosendin Electric, San Jose.

The team selected the Precision estimating program, developed by Timberline Software Corporation, Beavertown, Oregon, to connect to the CAD program (which was created by Autodesk, San Rafael, California, then modified and supplied by Ketiv Technologies, Portland, Oregon). The estimating program also linked to the scheduling software, Schedule Simulator, created by Jacobus Technology, Gaithersburg, Maryland.

The design-cost integration was complicated because there was no central estimating database containing all the items necessary to create accurate and detailed cost estimates. However, as the project team applies this technology to more projects and their estimating database grows, the process will become faster and easier.

To integrate design and cost data, the team entered into Hathaway's database 314 items defined by the subcontractors that required cost estimates. Hathaway had a database of such general items as walls, but the subcontractors specified items in detail, for example, ductwork, drywall, and metal wall studs, as well as labor costs, which led to more accurate estimates. The subcontractors each spent an average of three hours entering items related to their disciplines.



THE DESIGN/BUILD *team linked each element of the 3-D CAD design of the plant to cost-estimating and scheduling software.*

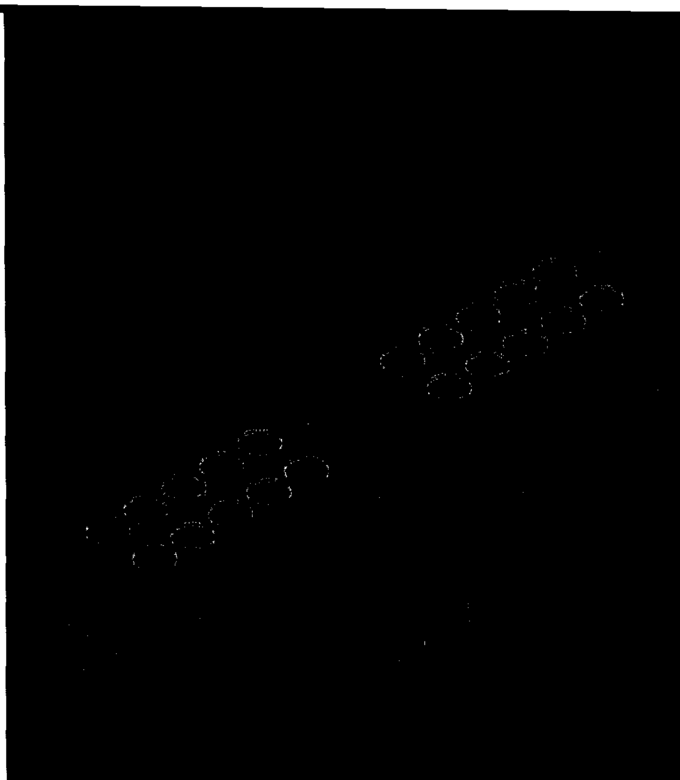
Next, the team used formulas to convert the estimating items into usable quantities that could be extracted from the CAD drawings. For example, the formula for the cost of the metal studs for a wall might be determined by the height and length of the wall, the spacing between the studs, and the cost of the studs themselves. This step is particularly important when using linked design-cost software, because the variables specified in the formula will be automatically linked with the CAD elements when the estimate is created. Careful correlation of the estimating variables with the CAD variables ensures that accurate data (for example, the total cost of a section of wall or the cost of just the drywall) can be extracted from the CAD model. This task took a total of six hours.

Third, the team grouped estimating items into work packages and tables. This was necessary because extracting a quantity (or takeoff) from a work package is typically more efficient than going item by item and because the design-cost link allows only one estimating record to be attached to each CAD entity. Grouping required 12 hours.

Fourth, the CAD model was modified to include all the estimating items. For example, a wall that had been designed as one object was broken into two objects because part of it extended to the full height and part was an interior partition. These modifications took four hours.

Next, work packages and items were attached to each CAD model. The architectural model contained 117 entities; the HVAC model, 185; the electrical model, 1,564; and the piping model, 3,139. The total duration of this task was 12 hours. And finally, estimates were produced and adjusted, a step that took about 10 hours.

After completing the connections between design and cost information,



The design for the pharmaceutical plant included chillers, pumps, and heat exchangers outside of the main building.

the team began working on incorporating the time element. A particularly detailed 4-D model was needed in this project to coordinate the mechanical, electrical, and piping work with the equipment installation on the mechanical platform.

The design and schedule data were integrated in four steps. First, Hathaway's schedule, containing more than 800 activities, was modified to reflect detailed subcontractor sequencing and work flow that were segmented into zones. The total duration of this task was eight hours.

Second, CAD layer names were changed to correspond with the activity names and work breakdown given in the schedule. This task required 12 hours and involved creating new layers, renaming old ones, and moving CAD objects to the appropriate layer. For example, the HVAC design model originally contained 6 layers, but after the model was modified to correspond to the schedule activities, there were 22.

After this restructuring was complete, the planner simply executed a program that linked the Schedule Simulator model to the CAD model by matching the activity names with the layer names. (Alternatively, a planner could perform this linking manually rather than modifying the activity names in the Schedule Simulator model and the layer names in the CAD model.) Finally, the grouped objects were linked with the schedule activities. This manual linking took four hours.

Design-schedule integration was particularly complicated because most CAD models are created without consideration of how the designed objects will fit together as they are constructed. This problem will fade as CAD systems become more object oriented to allow easier manipulation of CAD objects.

Hathaway reduced the estimating time by 25 percent by using this electronic design-cost integration. In addition to saving time, the CAD-estimate link provided electronic verification that all of the objects in the design had been included in the estimate. The electronic estimates also provided a record of how the quantities were derived.

In addition, the project manager for Hathaway found the 4-D models to be useful in coordinating construction tasks and communicating the intent of the schedule. The 4-D model was particularly helpful in communicating the plan for equipment installation and coordinating the mechanical, electrical, and piping trades on the equipment platform. Hathaway plans to use electronic design-cost-schedule integration on future projects.

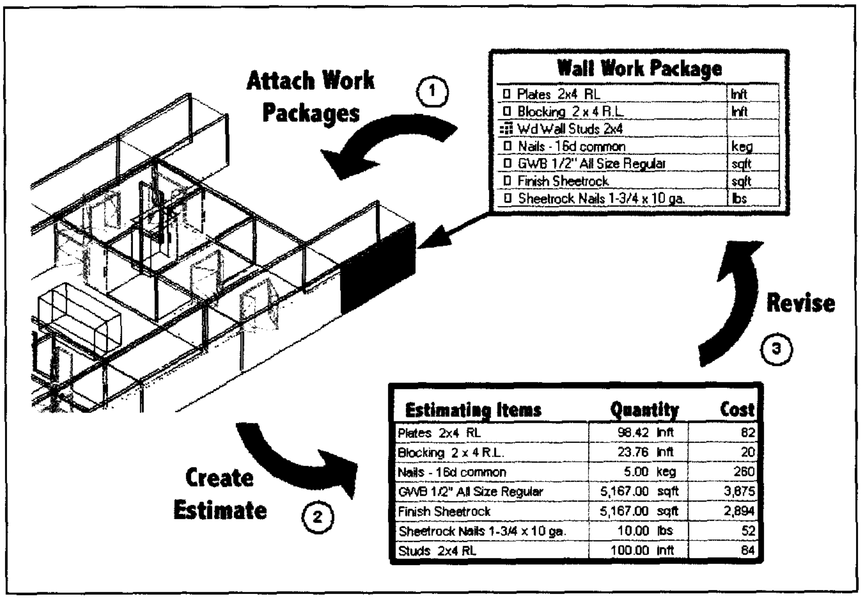
Project designer Flad also benefited from the model. Traditionally, Flad would have created 2-D plans and elevations separately. Here, however, the firm created plans and elevations in a single time-cutting step. This link was particularly useful when the design changed, because the company could make all modifications to one model.

One key lesson learned is that every essential trade on the project should put its design into the 3-D model. The structural work, which was only partially modeled in 3-D, and the fire sprinkler work, which was not modeled in 3-D at all, led to the only interference problems during construction.

There are also some limitations to the current integration technology:

- The design-cost integration software can extract only certain types of information from the CAD model. This limitation forced the HVAC and electrical subcontractors to change their drawing processes in some cases so that the appropriate dimension could be extracted.
- The user must always manually select the estimating item that is associated with each CAD object. Ideally, estimating items would be linked automatically based on the corresponding CAD variable. For example, the appropriate work package would be automatically selected for pipe objects based on the pipe diameter.
- Only one work package can be attached to each object in the CAD model. This limitation becomes important when a CAD object is associated with multiple estimating items that are not typically included in the same work package. For example, painting would not typically be included in a wall work package. To calculate the quantities for painting automatically, the user would need to include painting in the wall work package or create a separate paint object in the CAD model.
- When creating CAD models, designers typically do not focus on how contractors will assemble the building components. As a result, the planner needs to modify the model so that the CAD objects can be related to the associated schedule objects. Linking the CAD model to

The Design-Cost Integration Steps



the schedule model requires significant understanding of how the software creates objects and classes.

The Sequus team found that changing technology meant changing partnerships. Team members that create buildings through a design-cost-schedule integration method must learn to take on new responsibilities and to share old ones. Owners must bring the team together early in the design process so that all members can develop detailed 3-D CAD models collaboratively. No single organization has the expertise required to build a complete and accurate 3-D model.

In the future, general contractors will need training in CAD software so that they will be able to manipulate the models and interpret how they should be drawn. In addition, contractors will need to provide input to designers so that the CAD objects are drawn in a way that supports automated quantity takeoffs. Finally, general contractors are likely to become the keepers of the models, accepting information from the designer and parceling it out to the subcontractors. This flow of information will continue throughout the project as design changes are incorporated and propagated.

Under this model, designers will spend more time orchestrating the collaborative design process and less time performing detailed design. They will establish the overall design process, develop specifications, and work closely with all members of the project team, especially the general contractor. This process will allow the appropriate CAD dimensions to be extracted from the architectural design for design-cost-schedule integration. For example, as Flad and Hathaway worked together to develop the Sequus design, Hathaway advised Flad to draw polylines for the ceiling and flooring so that the area could be extracted for estimating purposes.

In addition, subcontractors will become more active in the early phases of the design as the architect and engineer develop the specifications and schematics that form the basis for subcontractors' designs. The subcontractors' detailed designs will still need to be approved by the architect and engineer through the shop drawing process, but subcontractors will need to develop CAD modeling capabilities to benefit from this involved process. Also, as subcontractors become more active in the design, they will become better able to assist the general contractor in coordinating the work of subcontractors throughout project delivery.

Although owners, designers, and builders of facilities will need to develop new skills and greater flexibility to seize its benefits, design-cost-schedule integration can eliminate the inefficiency and redundancy in today's project management processes. The resulting benefits will include shorter estimating times, fewer takeoff errors, better documentation, accurate reproductions of the estimating process, and more effective communication of the construction schedule. Together these improvements will help construction professionals meet the increasing demands for a shorter, error-free project delivery process. ▼

Sheryl Staub is a project engineer for Hathaway/Dinwiddie Construction Group, Santa Clara, California. Martin Fischer is an assistant professor in the Department of Civil and Environmental Engineering at Stanford University. Melody Spradlin is a project executive for Hathaway/Dinwiddie Construction.

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