DYNAMIC 3D VISUALIZATION OF CONSTRUCTION ACTIVITIES

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Abstract—*Construction companies large and small are being called upon to "do more with less" by building ever-more-complex plants in shorter timeframes with fewer resources. In this context, the use of a robust 3D visualization suite can contribute to project efficiency by helping to optimize materials and equipment, reduce lost inventory, provide greater predictability, lower costs, and improve worker safety. This paper examines ways in which Bechtel has been using 3D visualization in conjunction with other tools and techniques to improve construction performance and productivity. Specific examples are provided of how Bechtel is integrating 3D visualization with both in-house and externally developed software and work process improvement initiatives. The results have brought the company closer to achieving its overall strategic vision of being able to identify, integrate/aggregate, and ultimately deliver timely and validated information to projects in a manner that consistently enables quality work to be performed safely, effectively, and efficiently.*

Keywords—*3D model; 4D model; computer-aided design and drafting (CADD); Construction Owners Association of Alberta (COAA) WorkFace Planning; engineering; engineering, procurement, and construction (EPC); integration; Intergraph SmartPlant Review; lean construction; technology; visualization*

INTRODUCTION

Construction operations have been modeled in three dimensions for many years. Three-dimensional (3D) modeling is a powerful, objective function evaluator well suited to designing complex resource-driven construction processes. The current state-of-the-art simulation systems allow complex construction operations to be modeled in great detail and with utmost flexibility. 3D analysis reveals meticulous details about planned operations before actual field implementation commences. Such details include resource utilization, resource idleness, operational bottlenecks, production rates, and the resulting costs.

The ability to create 3D visualizations of construction operations can be of substantial help in communicating the authenticity of a simulation analysis to construction decision makers. In addition, a visualization can provide valuable insight into the subtleties of the modeled construction operations that cannot be otherwise quantified and presented. The ability to realistically model construction operations can thus enable planners to provide more pragmatic and comprehensive feedback to construction personnel.

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MAJOR ISSUES RELATED TO CONSTRUCTION PROJECT DELAYS

Construction project delays are frequent and recurring. The principal factors causing these delays are comparable across developing countries. Additional local factors pertaining to industry, socio-economic, and cultural issues, along with project-specific characteristics, further contribute to delays. The most significant factors causing construction project delays are as follows (also see **Figure 1**):

- Poor communication among disciplines and functions
- Concurrent engineering—design and construction going on in parallel
- Unavailability of engineering drawings
- Material unavailable or unallocated
- Delayed delivery of items from fabricators
- Schedule pressure on fast-track projects
- Limited resources
- Aging skilled workforce—younger, less-experienced craft workers
- Many revisions during the project
- Scheduling by area, turnover by system
- Tendency to work with whatever is available
- Operation in "scramble mode" to try to achieve schedule

ABBREVIATIONS, ACRONYMS, AND TERMS

3D	three-dimensional
4D	for the purposes of this paper, 3D plus time
4D CADD	process used to compile 3D CADD models in a time-phased manner to depict a construction sequence
AFC	approved for construction
API	application programming interface
BPS	Bechtel Procurement System (Bechtel's integrated supply chain and materials management system for E&C projects; designed for use throughout a project's life for procurement of engineered equipment, bulk materials, and services) (a BSAP)
BSAP	Bechtel Standard Application Program (Bechtel uses BSAPs corporate-wide as the standard software for specific functional or corporate business processes.)
CADD	computer-aided design and drafting (a typical project 3D CADD model contains piping; equipment; concrete; structural; maintenance/safety; heating, ventilating, and air conditioning; and electrical and instrumentation design elements)
COAA	Construction Owners Association of Alberta (Canada)
E&C	engineering and construction
ELT	erect line and tack
EPC	engineering, procurement, and construction
FIWP	field installation work package (a WorkFace Planner element)
GBU	(Bechtel) global business unit
IFC	issued for construction
IT	information technology
MRR	material receiving report
PDS	plant design system
SEC	Software Engineering and Construction (part of Bechtel Information Systems & Technology)
SETROUTE®	Bechtel-developed automated engineering, design, and construction management system for electrical cable, raceway, and wiring (a BSAP)
SQL	structured query language (used to manage data in relational database management systems)
SSRS	SQL Server Reporting Services (Microsoft® Corporation's server-based reporting platform that provides comprehensive reporting functionality for a variety of data sources)
***TEAM**Works*™	Bechtel-developed system for tracking equipment and reporting materials and quantities (a BSAP)
WFP	WorkFace Planning (a Best Practice of the COAA)

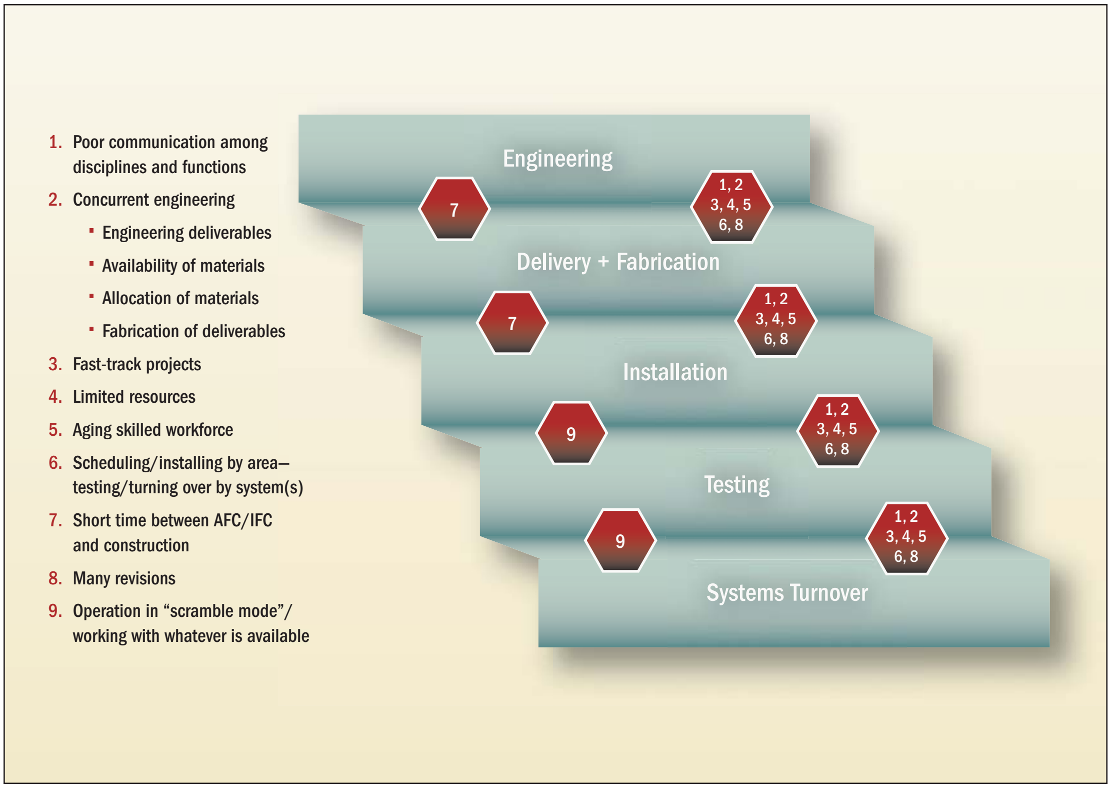
Project delay factors can be avoided or controlled by implementing powerful and versatile 3D visualization solutions in conjunction with other tools and techniques developed to improve construction performance and productivity.

These delay factors pose the following questions:

- Is the planned schedule achievable?
- What is the exact progress to date?
- How do engineering changes affect work content, cost, and schedule?
- How is the schedule maintained in view of changing circumstances?
- What effort is needed to complete the project?
- What is the impact to the project if materials are delayed?

THE ROLE OF POWERFUL AND VERSATILE 3D VISUALIZATION

Some of the construction project delay factors and questions listed above can be avoided or controlled by implementing powerful and versatile 3D visualization solutions in conjunction with other tools and techniques developed to improve construction performance and productivity. This paper examines Bechtel's use of Intergraph® SmartPlant® Review—a robust, industry-leading 3D visualization suite—and provides examples of how Bechtel has been able to integrate its capabilities with both



(Image courtesy of Bentley Systems, Incorporated. Used by permission.)

Figure 1. Construction Project Delay Factors

Installation progress and remaining installation tasks are visually monitored.

in-house and externally developed software and work process improvement initiatives. Through this approach, the company has moved closer to achieving its strategic vision of being able to identify, integrate/aggregate, and ultimately deliver timely and validated information to projects in a manner that consistently enables quality work to be performed safely, effectively, and efficiently.

3D Visualization Tools and Techniques

An animated construction sequence has proven useful on projects in helping to avoid planning overlaps, among other things. [1] As a deliverable for work contractors, the underlying model should be updated daily for the duration of the project. In order for the model to remain the central source of project information, it is important for the engineering team to maintain the model's integrity by using redline strikeout and as-built drawings from start to finish. Tools and techniques for capturing the information that needs to be incorporated include the following.

Work Package Planning

Work package planning can assist in constructing work packages. SmartPlant Review can highlight the components of a group of isometrics within a view (by color) and supports the planning process by using colors to display procurement information (delivery, fabrication status, etc.) about various work package commodities. [2]

Progress Visualization

Progress visualization can be supplemented by progress information taken from various Bechtel project information systems (***TEAM****Works*™, SETROUTE®, BPS, etc.) and can be graphically displayed by color code in a tool such as SmartPlant Review. The 3D visualization can be populated with information from these systems and can be viewed at SmartPlant Review workstations. Progress visualizations can be configured to be automatically updated daily. [2]

Organization by System

The engineering model can be reorganized by system for testing and turnover. Doing so enables installation progress and remaining installation tasks to be visually monitored on a system-by-system basis. As the project transitions from installation by areas to testing of systems, daily installation activities can be reprioritized and focused to prepare systems for testing in the required sequence and timing. [2]

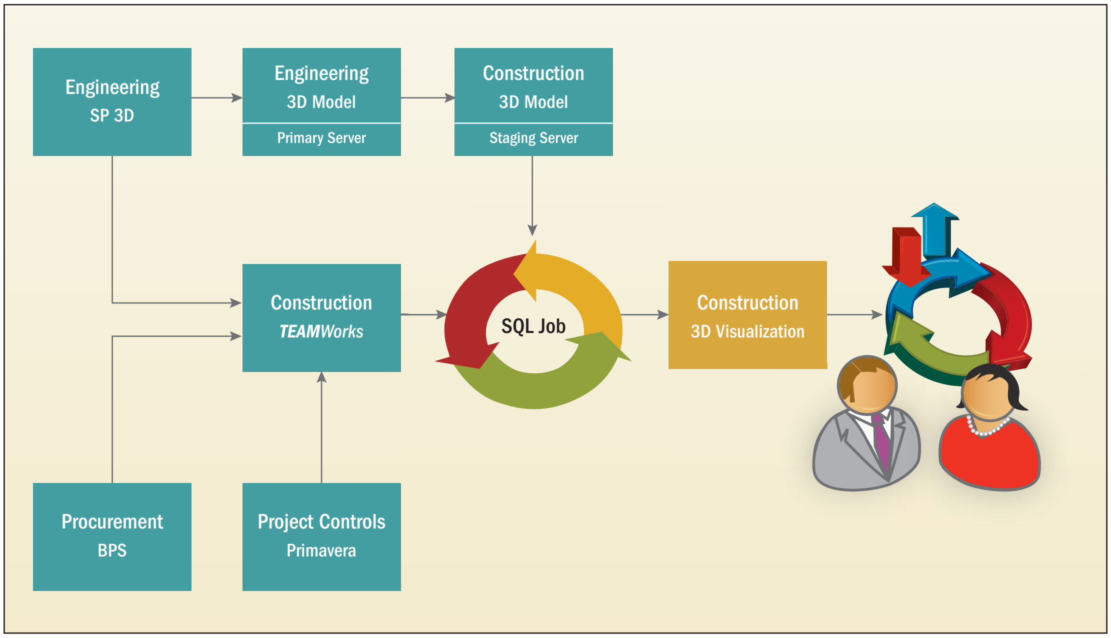


Figure 2. Data Flow Diagram of 3D Visualization Integration with BSAPs

Procurement and fabrication can be monitored and tracked for materials released for construction.

Material Availability

The procurement and fabrication processes can be monitored and tracked for materials released for construction. The daily arrival of pipe spools, for example, can be visualized so that crew resources can be directed to target installation work in areas where materials are available. [2]

Integration of 3D Visualization with Bechtel Standard Application Programs

3D visualization, which is based on application programming interface (API) modules, automatically organizes the engineering design model into constructable elements so that the virtual model represents the way the facility is built, not just the way it is designed. A data flow diagram depicting how 3D visualization is integrated with Bechtel Standard Application Programs (BSAPs) is provided in **Figure 2**. Some of the additional detail relates to information that can be provided by the Engineering and Procurement disciplines as deliverables. The division of responsibility among all the disciplines is shown in **Table 1**.

Table 1. 3D Visualization Division of Responsibility

Task
Establish ownership of 3D visualization
Provide list of required files to create placeholder in SmartPlant Review model set
Coordinate with Engineering and Procurement
Create placeholder in SmartPlant Review model set
Create interface between ***TEAM**Works* and BPS
Install and configure Microsoft® SQL Server
Map the fields in ***TEAM**Works* to the labels in SmartPlant Review output
Schedule run time to immediately follow the project SmartPlant Review output routine
Review modified output in the SmartPlant Review graphic user interface
Validate the data
Instruct the field team in creating and using display sets and how they apply to the new ***TEAM**Works* data included in SmartPlant Review
If ***TEAM**Works*/BPS report does not satisfy user needs, direct user to SSRS team to have new reports developed

Throughout the ongoing process of integrating 3D visualization with BSAPs, engineering coordination plays an important role. During the engineering and procurement phases, engineering coordination facilitates:

- Common naming conventions and standard attributes across the disciplines
- The use of BSAPs to produce standard design practices and procedures

During the construction phase, engineering coordination facilitates:

- The accommodation of work scope variations that may necessitate the incorporation of additional engineering deliverables and data content into the model
- The development and incorporation of the labels required for construction

Information exchanges are triggered manually or automatically at the discretion of the plant design system (PDS) coordinator for the project. Depending on the phase, strategy, and scope of work for the project, the interval of updates varies and is also at the discretion of the PDS coordinator.

The exchange of flat files is nonstandard in that the mechanism, timing, and content configuration vary from project to project. Factors that affect these variables are network connectivity and bandwidth, available engineering resources for the project, and the construction scope of work.

Information is exchanged via a database connection between the *TEAMWorks* visualization application, the SmartPlant Review database (Microsoft Access), and the *TEAMWorks* database server. The utility has no user interface and, once configured, runs on a job schedule. This step should be synchronized with the planned SmartPlant Review dataset synchronization and the planned quantity reporting cycle in the field.

The exchange process works by finding tags in *TEAMWorks*, gathering the configured status data, and writing it to the existing labels in the SmartPlant Review dataset based on matching tags between the model and *TEAMWorks*.

Work scope variations may necessitate the incorporation of additional engineering deliverables and data content into the model.

Viewing *TEAM*Works Object Data in 3D Visualization

Object data that includes *TEAMWorks* and BPS information can be viewed for any tagged object in the 3D model via SmartPlant Review. By selecting the "auto-highlight" option on the menu, pressing the mouse button, and pointing to any component in the main view, a user can see the object data in an adjacent text view window (see **Figure 3**). Thus, information such as isometric sheet and assorted *TEAMWorks* data can be seen against the visible object. (However, this interface does not support input to *TEAMWorks*.) In the piping spool example shown in Figure 3, the circled spool is represented in the Object Data box to the right. The material receiving report (MRR) attribute shows "1," meaning that a value is present in *TEAMWorks* and that the commodity has been received by BPS. The referenced module has also been toggled on to show a scale reference. All pipe displayed here has been received.

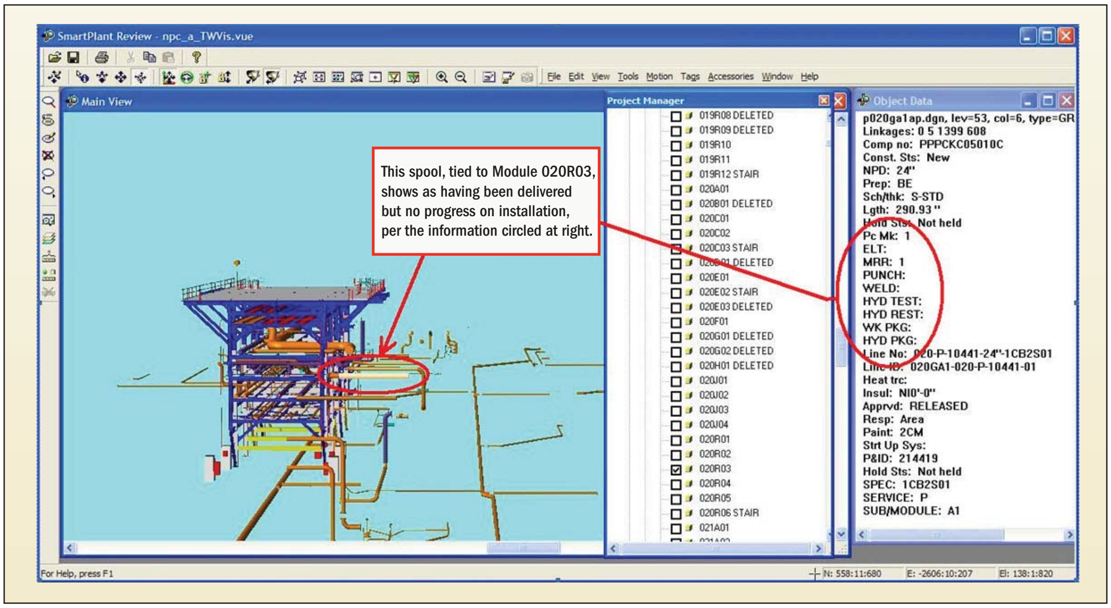


Figure 3. Example of *TEAMWorks* Object Data in 3D Visualization

Data is collected from ***TEAM**Works* for the attributes listed in **Table 2**.

Table 2. Data Attributes

Attribute	Description
MRR	Material Receiving Report*
ELT	Erect Line and Tack*
PUNCH	Punchlist Complete*
WELD	Weld Complete*
HYD TEST	Hydrostatic Test Complete*
HYD REST	Hydrostatic Restore Complete*
WK PKG	Work Package Number present in ***TEAM**Works* for any object
HYD PKG	Hydro Package Number present in ***TEAM**Works* for any object
SYSTEM	System Number present in ***TEAM**Works* for any object

* A value of 1 indicates that there is data in ***TEAM**Works*.

3D visualization is integrated with WFP to improve planning and reduce overall construction cost.

Figures 4, 5, and 6 respectively illustrate how integrating 3D visualization with BSAPs facilitates viewing ***TEAM**Works* object data to pinpoint material availability, progress, and organization by system (three of the 3D visualization tools and techniques discussed earlier in this paper).

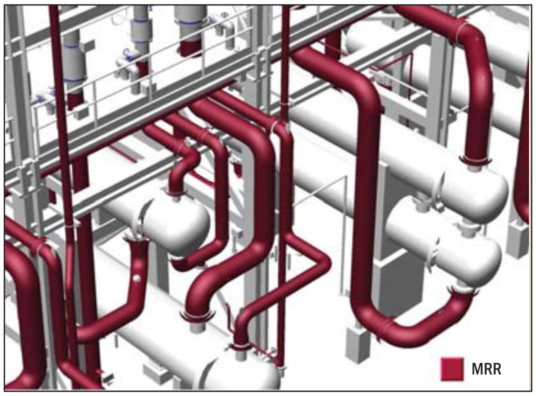


Figure 4. Material Availability

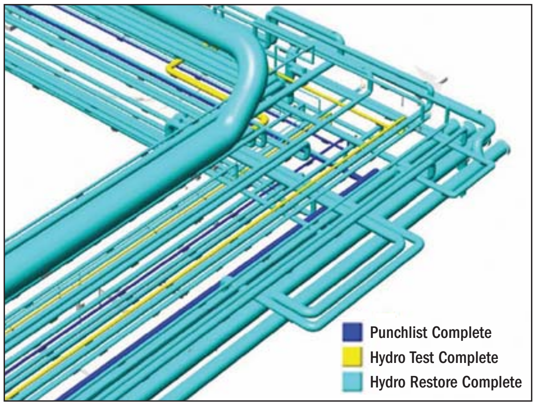


Figure 5. Progress

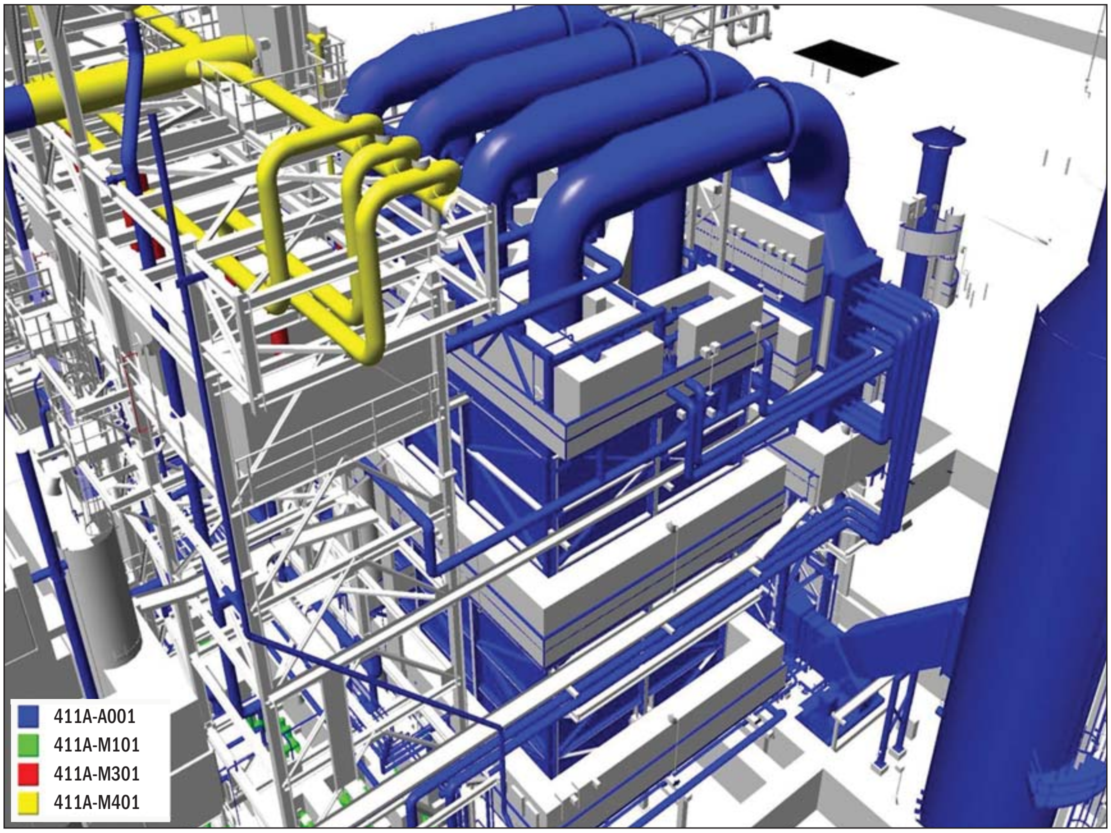


Figure 6. Organization by System

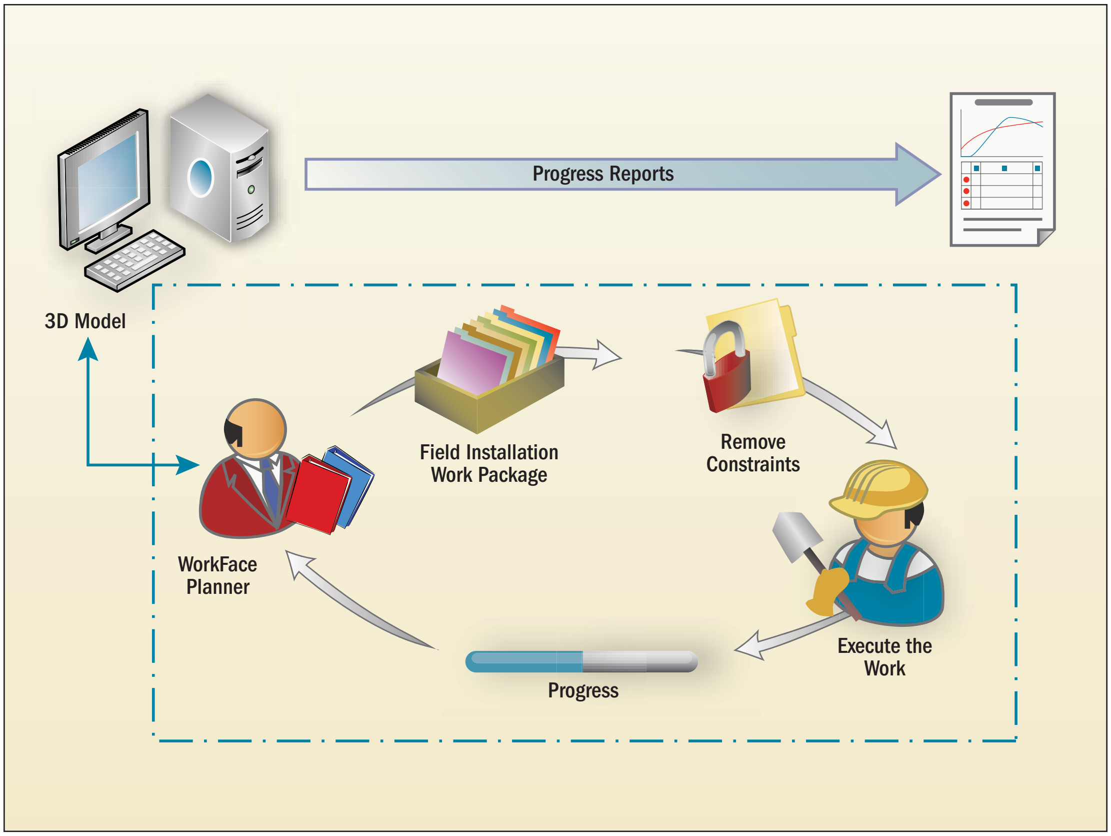


Figure 7. WFP Integration with 3D Visualization

The 3D model plays an important role in establishing a knowledge center.

Integration of 3D Visualization with COAA's WorkFace Planning Process

WorkFace Planning (WFP) is an initiative being investigated by the Construction Owners Association of Alberta (COAA). As stated on the COAA's website, "WFP is the process of organizing and delivering all elements necessary before work is started, to enable craft persons to perform quality work in a safe, effective and efficient manner." [3] Bechtel is currently working on ways to integrate 3D visualization with WFP to improve planning and reduce overall construction cost.

WorkFace Planners are responsible for developing field installation work packages (FIWPs) for the construction contractor's workforce. FIWPs, which are developed for the parts of the project where engineering is complete, convert construction work packages into lists of assigned tasks for work crews and ensure that the required resources and information are in place before work starts. A typical WorkFace Planner develops and maintains FIWPs in one discipline for one general foreman or approximately 50 craft employees.

The WorkFace Planner typically uses 3D models to design virtual plans based on the schedule and the superintendent's execution plan. The WorkFace Planner then identifies and removes the constraints for each FIWP and enters progress once the plans have been executed. The 3D model plays an important role in establishing a knowledge center that allows WorkFace Planners to access real-time project information. A simplified work process diagram of WFP integration with 3D visualization is shown in **Figure 7**.

EPC BENEFITS

Using 3D visualization during the project engineering, procurement, and construction (EPC) phases:

- Increases workflow efficiency and reduces costly errors and rework
- Reduces the risk of project overruns by making accurate information available whenever and wherever it is needed
- Improves predictability
- Improves construction productivity
- Reduces schedule
- Enables data to be compared among various contractors

3D visualization can positively affect both the preconstruction and construction phases.

IMPLEMENTATION

It is becoming increasingly important to manage a project's entire lifecycle: engineering, project management, procurement, material management, fabrication, and installation. To this end, 3D visualization has already been implemented on several major Bechtel projects, including:

- Shell Scotford Upgrader Expansion 1 (SUEx1) in Alberta, Canada, which has increased the upgrader's capacity to process bitumen into synthetic crude oil
- Motiva oil refinery expansion at Port Arthur, Texas, which will increase production by 325,000 barrels per day when completed in 2011 (making Motiva the US's largest refinery)
- Angola liquefied natural gas facility, which will produce 1 billion cubic feet per day of natural gas upon completion in 2012
- Duke Edwardsport integrated gasification combined cycle (IGCC) 630 MW power plant in Edwardsport, Indiana, the first commercial-scale IGCC plant in the US since the 1990s, scheduled for completion in 2012
- Pueblo chemical agent-destruction pilot plant near Pueblo, Colorado, which will destroy the chemical weapons stockpile at the Pueblo Chemical Depot in Colorado, starting as soon as 2015

FUTURE OUTLOOK

Construction planning can be interpreted from different angles, including making technology choices, defining work tasks, estimating the required resources and durations for individual tasks, and identifying interactions among the different tasks. The use of 4D CADD models [4] (intelligent, time-phased 3D CADD models that can be used for various construction activities) to carry out true collaborative planning is only beginning to be realized. It has been postulated that 4D models are currently being used more as planning review tools, rather than being integral to the initial construction planning process [5], and have generally not yet been engaged to fully support multi-disciplinary collaborative construction planning by the teams involved.

As advancements continue, however, 4D models will eventually become the standard for all phases of facility design, engineering, and lifecycle engineering with regard to operation, maintenance, and retrofit. Bentley® ConstructSim® and Intergraph SmartPlant Construction are two examples of 4D CADD tools currently available on the market. As these tools mature, they may become suitable alternatives for 3D visualization.

Bentley ConstructSim

Bentley ConstructSim derives schedule data from 3D models instead of using schedule data as input. It optimizes a project by planning, sequencing, executing, and monitoring construction activities from within a virtual plant model. ConstructSim can be used to break up an engineering model and reorganize it the way it is actually built.

ConstructSim links project information technology (IT) systems—including 3D CADD model (all major formats: Bentley AutoPLANT®, Intergraph PDS®, AVEVA PDMS™, etc.), schedule, materials management system, project controls databases, and others—to create an integrated virtual environment that is kept constantly up to date.

Intergraph SmartPlant Construction

Intergraph SmartPlant Construction, a new SmartPlant Enterprise software module created specifically for process, power, and marine firms to more efficiently plan and manage plant, ship, and offshore construction, is said to foster increased productivity, accelerated project completion, and reduced risk.

By seamlessly integrating engineering, procurement, fabrication, and site materials, SmartPlant Construction facilitates improved work planning, efficient information exchange for better communication, and enhanced engineering and construction work processes.

SUMMARY AND CONCLUSIONS

The use of 3D visualization holds significant potential for the construction industry. Employing 3D visualization can positively affect both the preconstruction and construction phases by assisting planners in producing improved projects and then allowing them to see how their plans evolve. In addition, 3D technology enables planners to anticipate potential problems at the construction stage, which could have considerable cost and time implications. [6] And where 4D technology has been embraced, direct savings and increased productivity have been seen. The use of 3D visualization simulations allows considerable savings to be realized on construction projects by identifying problems before construction and avoiding rework during the project lifecycle.

In summary, the essence of using simulation to model construction operations is to obtain insights into the consequences of using different techniques and strategies, thus helping the planner to make the most advantageous decisions. Construction simulation systems provide users with detailed information such as material status, resource usability, and breakdown of the modeled system.

Bechtel's experiences to date show that if project requirements are accurately defined early and the right applications and work processes are put into place within Engineering, it is possible to deliver high-quality 3D visualizations along with the physical plants at a relatively small additional cost.

Clearly, the use of 3D visualization as a construction planning execution tool should be further explored for future large-scale construction projects. ■

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TRADEMARKS

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[2] Lean Construction Fact Sheet, Constructing Excellence, October 28, 2004, pp. 1–4, http://www.constructingexcellence.org.uk/pdf/fact_sheet/lean.pdf.

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ADDITIONAL READING

Additional information sources used to develop this paper include:

- Balfour Technologies, http://www.BAL4.com/.
- Bentley Systems, http://www.bentley.com/products/navigator.
- Common Point, http://www.commonpointinc.com/.
- Intergraph, http://ppo.intergraph.com/visualization.
- WorkFace Planning (WFP), http://www.coaa.ab.ca/productivity/workfaceplanning.aspx.

3D visualization simulations allow considerable savings to be realized by identifying problems before construction and avoiding rework during the project.

BIOGRAPHY

Shiva Krishnasamy is the field IT manager for the Shell Scotford Upgrader Expansion 1 project. Since joining the company in 1997, he has worked on multiple projects within Bechtel's Oil, Gas & Chemicals (OG&C) Global Business Unit, including Thai Plastic & Chemicals polyvinyl chloride facility expansion, BPC acrylics complex, Optimal butanol and derivatives facility, Goro nickel plant, CSPC Nanhai petrochemicals complex, and Thai Oil TPX facility revamp.

Shiva has 14 years of IS&T experience supporting EPC, with an emphasis on implementing technical innovations that add value and improve project work processes. While on the Shell project, he managed the EPC application portfolios and provided solutions for interoperability and data integration among these applications.

Shiva has authored a Bechtel white paper, plus four Bechtel Refined Intellectual Capital papers: (1) Automated Population of the Startup System Designator in Construction BSAPs, (2) Articulate Online – eLearning Solution for Project Office, (3) Using WinPCS on EPC Projects as a Startup Tracking Tool, and (4) iSCSI SAN for the IS&T Organization.

Shiva holds an MS from the University of Wales in Cardiff and a BS from the University of Greenwich in London, UK, both in Information Technology. He is a Six Sigma Yellow Belt.