3D PLANT DESIGN SYSTEMS: BENEFITS AND PAYBACKS

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Executive Summary

Cost, schedule and quality are the competitive drivers for process and power generation owner/operators and their engineering/construction contractors around the world. The business case for investment in 3D plant design technology is often decided by how this technology enables owner/operators and engineering/construction contractors to reduce construction and engineering costs; shorten design, construction and commissioning schedules; and improve operating efficiency, safety, environmental impact and regulatory compliance—all quality factors.

For more than a decade, computer-aided design has been used in the process and power generation industries for detail engineering; indeed, most engineering/construction contractors now use some form of CAD to produce engineering and archival documentation. Automated 2D drafting is a mature technology—by Daratech's estimate, there are more than 112,000 2D drafting screens in use by process and power generation firms and their engineering/construction contractors worldwide.

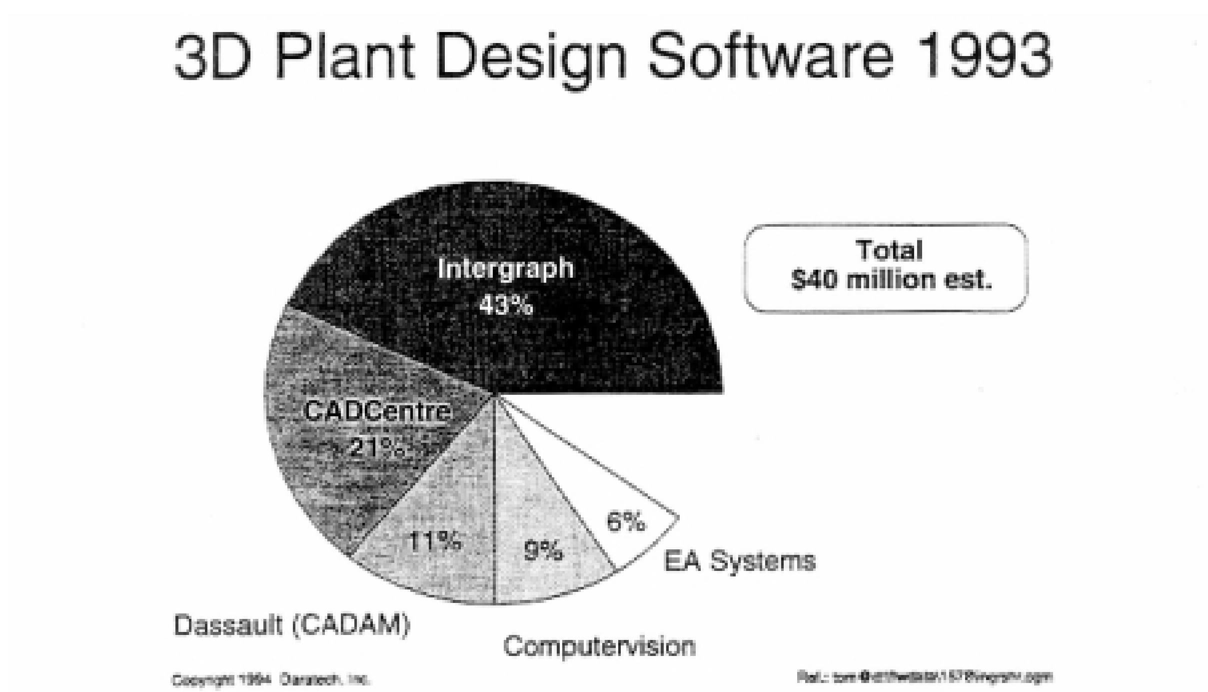

Figure 1

The use of 3D plant design is also pervasive in engineering/construction firms, with approximately 7500 3D plant design screens installed worldwide. These systems are used by all of the top 10 firms on the 1994 ENR Top 500 Design Firm list, as well as many other firms. The deployment of 3D plant design systems may be seen as differentiating firms that seek to leverage computer technology for competitive advantage from firms with more traditional engineering approaches. In this paper we discuss some of the benefits and challenges of the current use of 3D plant design technology, as well as trends for the future.

Plant Lifecycle Management Considerations

While some firms can justify their investment in 3D plant design technology on the basis of improved engineering efficiency alone, others look for returns on 3D technology investment in the construction, start-up, commissioning, maintenance and decommissioning phases of a plant lifecycle. From conceptual design to engineering to construction to start-up to operations and finally through revamp or decommissioning, 3D plant design technology is becoming a cornerstone of plant lifecycle information management.

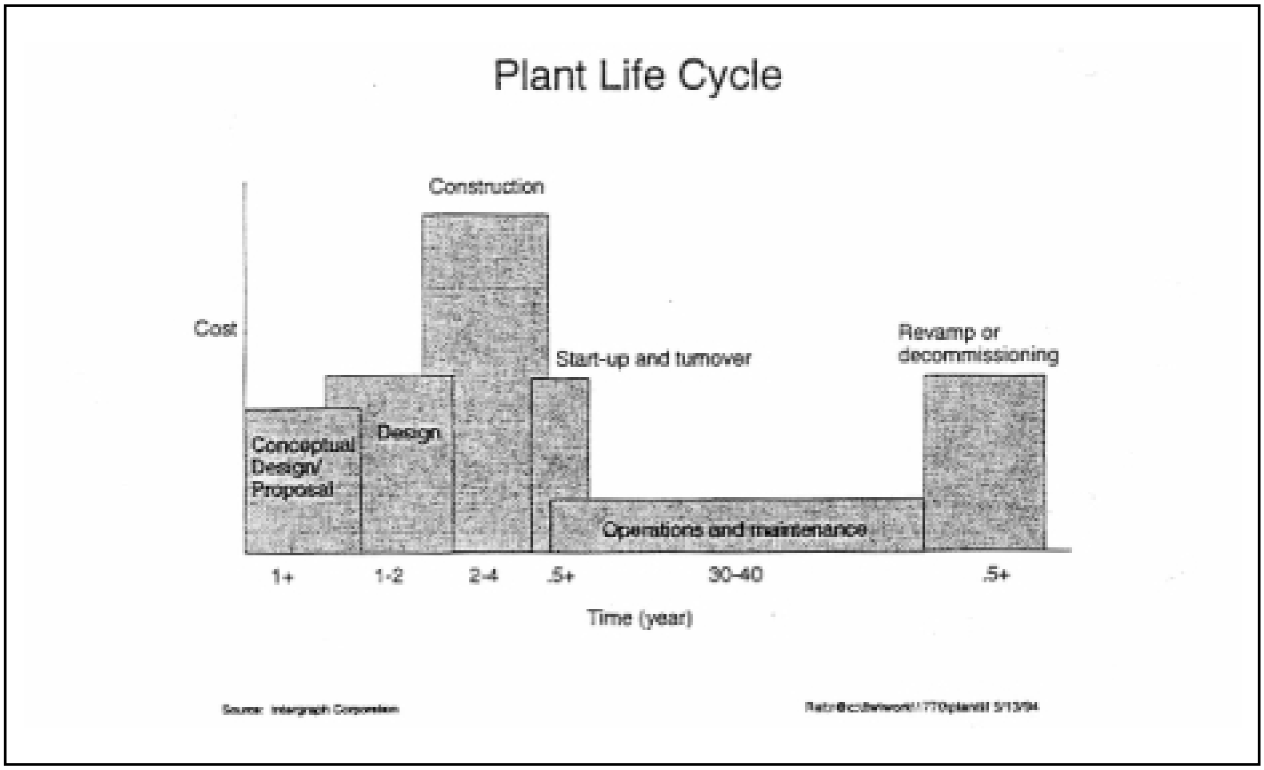

Figure 2

Owner/operators and their engineering/construction contractors are faced with technology investment decisions with long time horizons. Plants have very long lifecycles *[see Figure 2]*—forty or fifty years can elapse from groundbreaking through final decommissioning and cleanup of a given plant. On the other hand, plants are designed with computer hardware that typically begins to be outdated within 24 months, and with software applications that undergo major upgrades every three to five years. Thus, investing in computer hardware and software with a proven migration track record is an important strategic decision for the process and power generation industries.

Conceptual Design/Proposal Phase

Total process and power generation project costs are sensitive to conceptual design decisions — some owner/operators estimate that as much as 80% of project costs are committed during the conceptual design phase. Plant design software facilitates the economic analysis of design alternatives before project costs are committed. For example, 3D modeling enables design engineers to perform cost/benefit analysis for alternate plot plans.

Often one firm will conduct the preliminary design and produce the initial P&IDs, and another firm will complete the detail design. This process is more efficient and accurate if the P&ID data—the most important detail design deliverable—can be transferred in a usable form to third parties, particularly to downstream engineering/construction firms. This underscores the importance of P&ID software specification early in the design process for plant owners. Indeed, all users are looking for more intelligence and functionality to be built into P&ID software.

Accuracy and consistency of the documentation for conceptual design tasks, including process design and simulation, plant layout, cost estimation, process control specification, and equipment specification are critical determinants of project cost. Computer-aided conceptual design in general, and 3D design modeling in particular, can enable design intent to be communicated more efficiently and accurately among engineering personnel, which improves both quality and timeliness of project design.

A benefit particular to 3D modeling is that conceptual design information can be more readily communicated to non-technical personnel. Additionally, some engineering/construction firms report a favorable reception by senior management to animated 3D walkthroughs and photorealistic slide presentations at owner/operator client companies. Thus, engineering/construction firms can harness the visualization power of 3D modeling for business development purposes. In turn, some owner/operators have used 3D animations and slides produced from engineering designs to secure project financing.

While today's process simulation technology and plant layout and design technologies are mostly disparate, there is little doubt that future development will lead to better communication between the disciplines of simulation-based process design and plant layout and design.

Engineering and Detail Design Phase

For engineering and detail design of process and power generation facilities, 3D technology promises the benefits of improved quality through data integrity, consistency and standardization of design, constructability analysis, elimination of expensive plastic models, design and design segment re-use on future projects, input from operations at the design phase, automated interference checking, input data for engineering analysis and simulation, improved overall efficiency through automation of production of engineering drawings and reports, and better project control and coordination. Another benefit of higher-quality engineering is higher confidence in the overall project schedule. All these engineering and design considerations take on even greater importance in cases where design, management and operations functions are geographically distributed.

A strategic issue for both owner/operators and engineering/construction firms is the way project design costs are recovered from the owner by the engineering/construction firm contractor when 3D plant design systems are used. The challenge stems from the multifarious nature of process and power generation industry projects where there are many participants—owner/operator engineering departments, operations and maintenance divisions, design engineering/construction contractors and subcontractors, and others—each of whom may have separate profit-and-loss performance measures. Implementation of design automation technology is complicated when technical risk and economic costs and benefits of technology investments are shared among all these stakeholders.

In time-and-materials contracts—where operators reimburse contractor engineering expenses on a man-hour basis, and engineering progress is measured by the number of drawings produced—the economic incentive for engineering/construction firms to invest in more efficient technologies may be absent. In these cases, unless the owner specifies the use of a particular technology for a project, the engineering/construction firm may be unwilling to assume the expense or technical risk for adopting a new technology, encumbering the optimal implementation of automation technology. This may explain the accounting paradox that arises when contractor accounting departments sometimes view engineering plotting centers as profit centers rather than cost centers. On the other hand, the complexity of a large plant project often motivates owner/operators to use time-and-materials contracts to attempt to manage the costs of downstream engineering changes.

In lump-sum or fixed-bid contracts, where the technical risk of using newer technologies is borne by the contractor, part or all of the economic benefit of investing in and utilizing automation technology may be captured by the contractor. Indeed, a number of engineering/construction firms report that for lump-sum work, 3D plant design systems are the tools of choice. On the other hand, savvy owner/operators are well aware that their contractors are sometimes slow to reveal the productivity gains achieved by the use of technologies such as 3D plant design in order to protect their margins when bidding on projects.

Owner/operators may well profit from an analysis of contractor engineering costs—which typically represent 5% to 20% of total project costs—and may decide that while 3D methods can be 15% to 25% more expensive on an hourly basis, they may be 5% to 10% less expensive overall, because 30% to 40% fewer hours may be required to complete engineering documentation. But some in the industry believe the potential savings in construction rework offered by 3D methods dwarf the engineering cost savings, and more than justify all additional costs inherent in the 3D approach.

Users of 3D plant design systems mostly agree that the engineering product produced with 3D modeling is superior to that produced with manual or 2D methods. However, opinions about engineering productivity benefits of 3D modeling are more varied. Some engineering/construction firms report significant engineering productivity gains through use of the technology; other firms report that the main benefit is downstream construction savings. Most users agree that 3D modeling productivity is often sensitive to the experience and technical competence of the engineers and engineering supervisors, the core capability of the modeling software, the engineering work processes employed and the degree of integration between 3D modeling software and external systems such as for material control and piping specifications. Of course, measured productivity gains from 3D modeling may also vary depending on what criteria are used to measure productivity.

ICF Kaiser International (Fairfax, Virginia) reports significant engineering productivity gains from use of the technology. Table 1 shows an engineering and construction cost breakdown for a $140 million copper concentrating facility designed by ICF Kaiser International for Magma Nevada Mining Company. The plant, which is currently out for bid for construction, was designed using Intergraph PDS. According to Richard E. Nunes, Vice President and Chief Engineer at ICF Kaiser International, using 3D plant design software resulted in an estimated overall project savings of approximately $3 million, or 2.1% of the total project cost. Nunes estimates that $1.3 million of these savings came from reduced engineering costs (a 30.5% savings in engineering documentation costs), and the remaining $1.7 million will come from reduced construction costs. Animated walk-through presentations based on the 3D model were made to senior Magma Nevada Mining Company executives, and were subsequently used by Magma for investor financing presentations.

End users consistently report that reduced errors and higher-quality designs can be obtained using 3D models compared with using 2D or manual methods. For example, the integration of piping specifications and code requirements as well as ANSI and DIN standards in a consistent database allows engineers to avoid costly mistakes by trapping errors and out-of-specification design. A related benefit is that 3D models can be automatically exported to analysis applications to test the designs for mechanical stress, hydraulic analysis, thermal stress and other factors, which can both improve design quality and reduce project cost. Often, the earlier that design problems are detected, the easier and less expensive they are to resolve.

Interference checking between disciplines such as piping, HVAC, structural steel, electricity and the like is the most often cited benefit enabled by 3D plant design systems: the bigger and more complex the design, the greater the potential savings. With 3D plant design systems, interferences may be flagged early in the design cycle, which has a positive impact on downstream construction costs. Moreover, the more advanced 3D plant design systems enable design engineers to review interferences graphically in order to assess their importance and relevance.

Magma Nevada Mining Company
Copper Concentrating Plant

	Manual	2D Drafting Basic CAE	**3D Modeling Full CAE**
Number of Drawings	909	909	875
Total Man-hours	107,744	94,318	66,373
Manual Drafting Hours	26,851		
CAE Hours		13,246	22,846
Direct Labor Rate	$25.00	$25.00	$25.70
* Burden Multiplier	2.1	2.24	2.54
Labor Rate	$52.50	$56.00	$65.28
Total Engineering Document Production	$5,657,000	$5,282,000	$4,333,000
** Other	$4,182,000	$4,182,000	$4,182,000
Total Engineering Cost	**$9,839,000**	**$9,464,000**	**$8,515,000**
Equipment Cost	$45,500,000	$45,500,000	$45,500,000
Construction Cost	$84,500,000	$84,500,000	$82,810,000
Total Project Cost	**$139,839,000**	**$139,464,000**	**$136,825,000**
Estimated Engineering Savings	-	$375,000	**$1,324,000**
% of Engineering Costs	-	4.0%	**15.5%**
Estimated Construction Savings			**$1,690,000**
Total Savings	-	$375,000	**$3,014,000**
% of Project Costs	-	0.3%	**2.1%**

* Burden includes CAE cost
** Includes project management, process/project engineering, procurement, project control, estimating, and startup and commisioning services.
Data reproduced with permission of ICF Kaiser International (Fairfax, Virginia)

Table 1

Another key benefit of 3D plant design systems is automated production of engineering drawings and reports. This provides a benefit at the drawing checking phase. For example, the effort required to verify consistency between general arrangement drawings and piping isometrics is reduced considerably because both drawings are produced from a common database. In contrast, wholly manual methods where drawings are produced by different individuals often require extensive verification.

In the process and power generation industries, government regulations such as OSHA 1910.119 require a hazard and operability review (HAZOP) prior to construction. Typically conducted when design is nearly complete, the review is often extensive, requiring a week or more to perform for a medium-sized facility by the operator’s team of safety, operations, construction, reliability assessment, project and commissioning personnel. The HAZOP consists of an evaluation of all equipment, line routing, instrument and control placement, safety equipment location, and access and exit facilities under a variety of operating conditions and upset conditions.

Using a 3D plant model to conduct HAZOPs can offer substantial benefits over using plastic models and drawings, or drawings alone. HAZOP reviews must be conducted every five years, or whenever significant plant modifications are made. Using a 3D model shows great promise for streamlining the review process, as changes to the model can be more easily visualized and controlled.

According to George Tolpa, Litwin Engineers and Constructors (Houston, TX), the principal advantages of using 3D plant design systems during a HAZOP are improved efficiency, quality of review and operability assessment. Tolpa says that a detailed, line-by-line review of a 500-line facility typically takes three weeks to complete using P&IDs, orthographic and isometric drawings. With a 3D plant design model, the review can be accomplished in one-third of this time, or fewer than five days. The time savings are significant because 15-20 people may be required for the review and operability assessment. Time can be saved because of the enhanced visualization capabilities, plus integration of physical layout data with process information, that the model provides. Operations and maintenance staff can confirm that the detail design meets the original design requirements, which reduces the cost of downstream field changes.

For the future, 3D plant design technology promises even greater benefits through better mechanisms for reusing existing design fragments, and integration with specialized analysis applications that will automatically explore large numbers of alternatives to achieve better, more fully optimized designs.

Construction Phase

Plant construction costs, including construction labor, equipment, and materials, for typical process and power generation projects represent approximately 80% to 90% of total project costs. The high capital cost of plant construction means that even modest construction cost savings of a few percent achieved by using 3D modeling translate into very substantial dollar savings and high marginal returns on 3D plant design technology investments.

Construction-phase benefits of using 3D plant design technology include compressed construction schedules, reduction in field rework labor due to improved interference detection, higher-quality documentation for job sequencing and craft work, more reliable and clearer status reporting and verification, and improved costing schedules. Some users report 10% savings in fabrication cost and 5% savings in bulk material costs for typical projects, resulting in overall savings of 5% to 10% on project construction costs.

According to The M.W. Kellogg Company (Houston, Texas), an engineering/procurement and construction contractor which has utilized 3D plant design systems since 1988, the major returns on the use of 3D modeling come from greater visualization during the construction planning phase, higher material accuracy and reduction of field rework during the construction phase of a project. Producer companies report that field rework labor can be as much as 12% of total construction labor for projects executed with manual methods. This rework can be reduced to as little as 2% of total construction labor when 3D plant design modeling is utilized during the construction phase.

Improved job sequencing for craft labor is another target benefit of 3D plant design systems. According to some engineering/construction firm executives, craft labor can spend up to 30% of the day waiting for the right materials and equipment to install. Construction sequencing can be improved by enabling craft contractors to interact with 3D visualization models—a method which results in more complete and timely communication than traditional interpretation of isometric and orthographic views. For example, engineering/construction firms report that 3D plant design enables improved approval mechanisms for fabrication. Work packages delivered to off-site fabricators can be configured to optimize piping components and spools for on-site construction.

Related to improved job sequencing is the capability for enhanced visualization of project status. Three-dimensional models can be color-coded to represent design, shop fabrication, delivery, and field installation, etc. which allows both on-site and home office managers better visibility of project status. Graphical project status reporting can be more accurate and timely than manual methods. End-users can expect tighter integration of project management software with 3D modeling technology in the future.

Engineering/construction firm contractors also report improved costing schedules because of 3D plant design deployment. Three-dimensional plant design databases can be used to generate bills of material and material take-offs automatically, which can lead to more accurate procurement, reduced bulk material surpluses, and consequently improved project cash flow. Live links from engineering schematics and the 3D model to component catalogs can also enable more intelligent procurement scheduling—engineering/construction contractors report up to 5% savings in material costs by using 3D models.

Owner/operators and their engineering/construction firm contractors report that effective deployment of 3D plant design systems can lead to overall project cost savings in the range of 5% to 10%. This is achieved by reducing engineering costs, minimizing field rework, shortening construction schedules, improving craft efficiency, and reducing bulk material and equipment costs.

Operations and Maintenance Phase

For some owner/operators, the potential operations and maintenance benefits of 3D plant design data exceed all others. Though this remains a controversial issue for many, a growing body of empirical data indicates that there are real and substantial benefits realizable in this area through the use of 3D systems. For example, owner/operators are beginning to look to 3D plant design systems to optimize maintenance scheduling, improve safety management, streamline component and drawing research for operations troubleshooting, provide enhanced training, and minimize facility turnaround and outage time.

Visualization of, and familiarization with, work areas for maintenance crews enables better planning, reduced planning costs and lower maintenance costs. As an example, modeling locations for electrical outlets, welding outlets, air breathing apparatus connections, eye wash stations, staging areas, safe routes, scaffolding and the like has enabled a nuclear power generation utility's maintenance and construction crews to plan their work in advance and complete it more efficiently. Visualization of the work space enables intelligent maintenance planning, a benefit more easily achieved with a 3D model than with 2D drawings and physical models.

Process safety management and other regulatory compliance concerns are additional drivers for owner/operators to extract operations and maintenance value from plant design databases. Process safety management focuses attention on the availability, accessibility and currency of key documents such as PFDs and P&IDs. In North America, OSHA regulations require key process safety documents to be in place before plant start-up, and be under change management for plant operations.

Barriers to using 3D design data for operations and maintenance purposes are both technical and historical. One technical obstacle is that the data useful to operations and maintenance staff typically includes only a subset of total engineering data—we believe as little as 10% of engineering data is useful for operations and maintenance purposes. Owner/operators, by contrast, face the wider problems of document and configuration management.

For example, mechanical/piping design engineers specify pumps in terms of type, horsepower, flow ratings, frame type, nozzle connections, etc. On the other hand, operations and maintenance personnel are concerned with a pump's maintenance history, ratings such as mean-time-between-failure, electrical connections, suppliers, control circuits, etc. The challenge is therefore to extract from the design database data that are relevant to operations and maintenance and to configure these data in a form meaningful and useful to the operations and maintenance organizations. This information must be maintained for the duration of the plant, and the challenge is to extract only the information that can be maintained for the plant lifecycle.

A related technical obstacle is that many of today's tools for 3D model manipulation are sophisticated and require dedicated, well trained experts equipped with expensive equipment to operate. Some owner/operators have suggested that a service opportunity for their engineering/construction firm contractors may be to maintain plant database models, serving their customers by electronic transfer of data.

Another significant technical barrier to using 3D plant design models for operations and maintenance purposes is that many existing plants do not have 3D models or even 2D digital models. However, in some instances, some plant owner/operators have found it cost-effective to create digital models of existing facilities using traditional walkdown methods.

A method of solving this problem now finding growing acceptance is close-range photogrammetry. Using this technique, an existing facility is photographed, the photographs are digitized, and this digital data is then processed to extract a 3D CAD model. Although photogrammetric techniques have been used for decades in mapping applications, recent advances in low-cost, high-performance graphics computing have made the technology practicable for revamp projects in some process and power generation industries.

Not all the obstacles to adoption of 3D plant design technology for operations and maintenance purposes are technical—sometimes there are substantial business-practice or cultural obstacles. In many cases, field operations management is under capital investment constraints and there is the perception that CAD technology is still very expensive. However, entry-level pricing for 3D plant design technology has shown dramatic decreases in the past decade which make it accessible to a broader audience. *[See Figure 3]* Moreover, the use of multimedia technology is seen by industry leaders to promise reduced training costs. By moving training to the desktop where it is available as needed, from the classroom where retention rates are relatively low, training methods that harness today's and tomorrow's digital media tools will be more cost-effective.

For the future, potential applications of 3D model data include integrating real-time plant I/O data for process monitoring and optimization. Navigation of ever-increasing amounts of plant data may require graphical user interfaces. Beyond steady-state analysis, real-time simulation and analysis of plant processes become possible with the coupling of as-built 3D geometry data with operations data. An extension of this is a capability for "intelligent" advisors for process control and optimization. Other opportunities for enhanced use of 3D plant design databases include providing links to plant-wide databases for equipment control and maintenance; GIS for environmental and crisis management; and facilities management.

Other Technology Investment Considerations

Some industry critics have contended that investment in 3D plant design technology is not justified, saying it doesn't work and isn't worth the time and trouble. However, the past ten years have seen dramatic improvements in hardware price/performance and software capability, which have enabled higher-function 3D plant design technology. We believe 3D plant design technology has come of age and begun delivering on its early promise as a productive tool for the process and power generation industries.

The investment required for 3D design modeling is significant and includes annual software license fees, hardware, hardware upgrades, training, hardware maintenance, software maintenance, software upgrades, and costs associated with upgrading in-house-developed applications. New software releases outgrow the original hardware; also, computer hardware must be upgraded regularly as existing hardware ages and becomes prohibitively expensive to maintain. Of these costs, the most visible are often the purchase-order line-item costs of hardware and software. Figure 3 shows that in the past ten years, the average seat price (hardware and software) for a 10-seat configuration of a plant design system has declined by a factor of 5.

Price decreases are expected for the future but at a lower rate. Most of the decline has been due to dramatic reductions in hardware costs. Resistance to adoption of 3D plant design technology is consequently lower.

An important off-the-balance-sheet asset of engineering/construction firms and owner/operators alike is the engineering knowledge base of their employees. Owner/operator managers seek to capture corporate engineering memory while downsizing engineering departments, and engineering/construction firms struggle to retain engineering knowledge assets in the face of volatile, project-driven staffing requirements. This problem is particularly acute in the U.S. utility industry, where some utilities' response to intense competition brought on by deregulation has been to nearly eliminate their engineering departments. The use of integrated 3D plant databases may offer some relief to the vexing problem of capturing and retaining engineering know-how for both owner/operators and engineering/construction firms by enabling design re-use and archiving of plant information in a retrievable form.

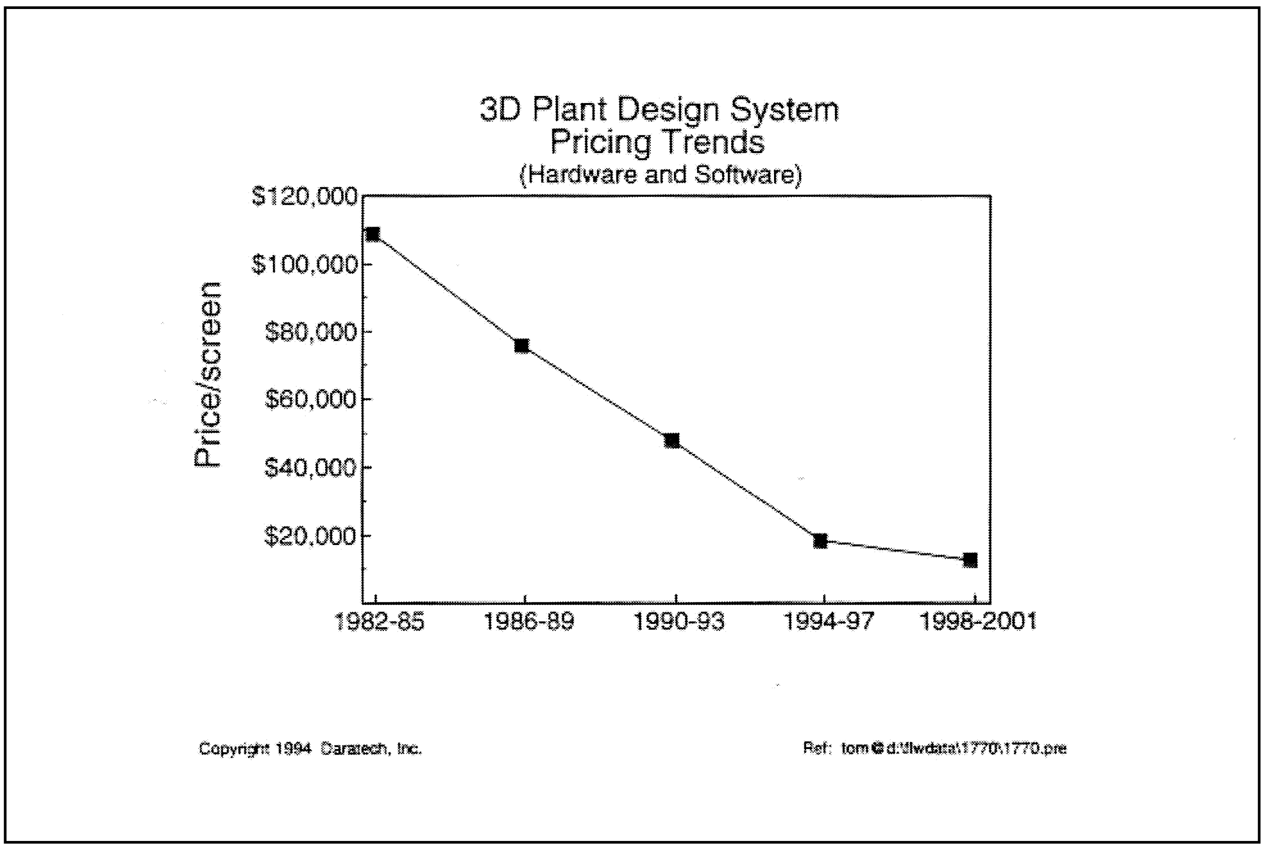

Figure 3

After a system has been in production for a number of years and design information has been accumulated and stored in the system format, software and hardware will typically represent only approximately 20% of total end-user investment in this technology. *[See Figure 4]* Approximately 70% of end-user investment in plant design systems will be in data and training. That is to say, switching from one system to another involves both operator retraining and porting much of the stored data. One reason why owner/operators and engineering/construction firms alike often elect to procure systems from market-share leaders is to protect this data investment and to reduce the probability that a port to another system will be required. *[Figure 1 shows Daratech's market share estimates for the 3D plant design software market in 1993.]*

Standards

Although great progress is being made in the development of data exchange standards, particularly standards based on the STEP initiative, it will be some time before these standards are fully operative. Consequently, owner/operators and their engineering/construction firm contractors who must manage projects for the complete plant lifecycle have taken a pragmatic approach by using market-leading technologies whose data formats have become de facto standards for the industry as a whole, or suppliers whose systems conform to these formats.

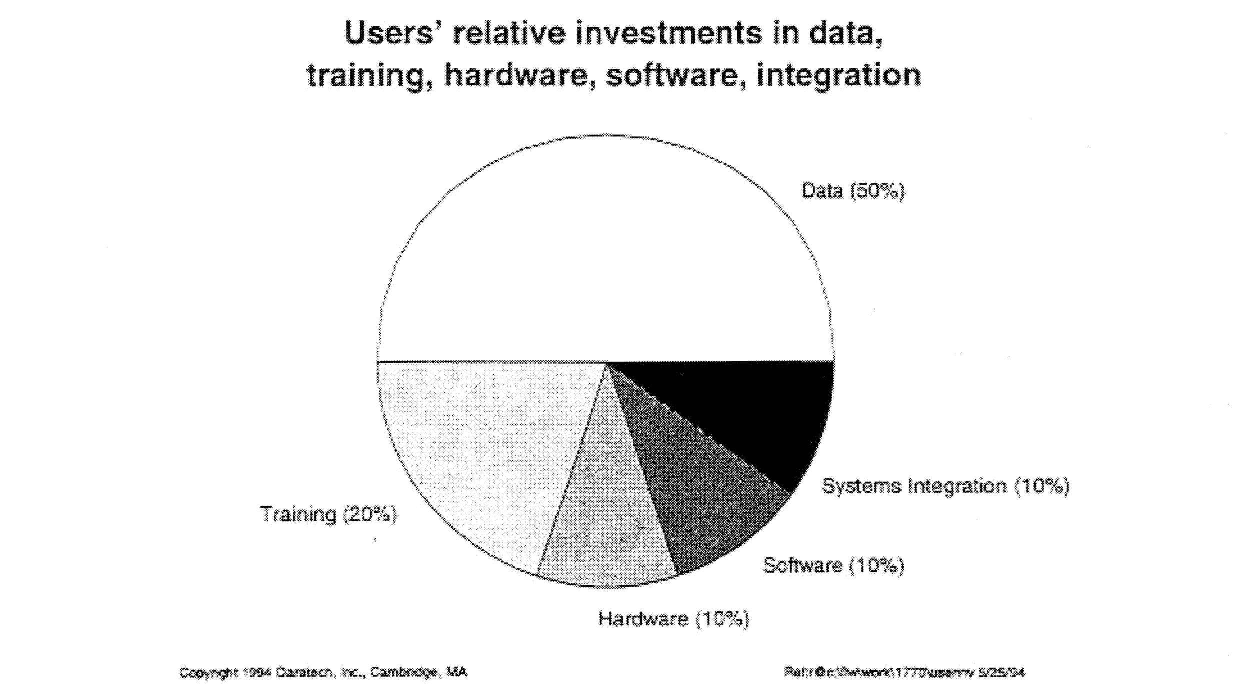

Figure 4

Conclusion

- Owner/operators and engineering/construction firms that use 3D plant design automation technology believe it reduces construction and engineering costs and shortens design, construction and commissioning schedules, and they are looking to this technology to improve operating efficiency, safety, environmental impact, and regulatory compliance for the complete plant lifecycle.

- The use of 3D plant design is pervasive in engineering/construction firms, with approximately 7500 3D plant design screens worldwide. All of the top 10 firms on the 1994 ENR Top 500 Design Firm list, as well as many other firms, use 3D plant design systems.

- Some firms justify their investment in 3D technology on the basis of improved engineering efficiency alone, while others have seen returns on 3D technology investment throughout the construction, start-up, commissioning, maintenance, and decommissioning phases of a plant lifecycle.

- A strategic issue for both owner/operators and engineering/construction firms is the way project design costs are recovered from the owner by the engineering/construction firm contractor when 3D plant design systems are used.

- Owner/operators and their engineering/construction firm contractors report overall project cost savings in the range of 5% to 10% by effectively deploying 3D plant design systems. This is achieved by reducing engineering costs, minimizing field rework, shortening construction schedules, improving craft efficiency, and reducing bulk material and equipment costs.

- We believe field experience and other evidence suggests that the potential operations and maintenance benefits of maintaining 3D plant design information exceed all others. A growing body of empirical data indicates that there are substantial benefits realizable in this area through the use of 3D systems including maintenance operations analysis, optimized maintenance scheduling, improved safety management, streamlined component and drawing research for operations troubleshooting, enhanced training, and minimized facility turnaround and outage time.

- Great progress is being made on the development of data exchange standards, particularly standards based on the STEP initiative, although it will be some time before these standards are fully operative. Owner/operators and engineering/construction firms alike often elect to procure systems from market-share leaders in order to protect their data and training investments.

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DARATECH, Inc.

This report on the benefits and paybacks of 3D plant design is complimentary from Intergraph Corporation.

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