Near-, Medium-, & Long-Term Benefits of Information Technology in Construction

By

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Near- Medium- and Long-Term Benefits of Information Technology in Construction

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Abstract: Information technology has been on a long slow path of implementation in the construction industry. The use of CAD is now the industry standard as is the use of e-mail, the World Wide Web, and a wide variety of personal computing software. The use of e-commerce services is growing and appears to be on the way to widespread commercial adoption, as are some data and document exchange standards. In spite of these successes, the AEC industry has been remarkably resistant to the cataclysmic business changes of consolidation, productivity improvement and globalization which have overtaken the automotive, aerospace and discreet manufacturing industries. In this paper we explore some of the near and long term information technology challenges facing the construction industry, and suggest how new information technology tools will enable three crucial new capabilities with the potential to create the profound changes seen in these other industries. First, new tools like 4D have grown out of the tradition of engineering CAD design. These new tools allow simulations of construction processes as well as visual simulations of the individual components. Second, transaction performance measurements (e.g. quantities of transactions and auditable trails of requests for information (RFIs), submittals, change orders, deficiency correction notices, etc.) which were up to now too expensive and time consuming to perform will become commonplace and virtually free. Third, improved data sharing with flexible product model schemas will permit the development of new contracting relationships, more geographically dispersed teams, and more tightly integrated supply chain performance. Depending on the investment time horizon, the specific challenges and tools available may change, but the overall direction is unmistakable. The AEC industry is about to experience a profound change: leaner organizations, more consistent and rigorous performance metrics, and relentless productivity improvements. The net result of these changes should also be increased profitability for those who are successful at mastering the new IT tools with the promise to enable these changes. This paper summarizes the ongoing research, development, and implementation of these new capabilities in early-adopter organizations and provides a roadmap to the short-, medium-, and long-term adoption by the AEC industry.

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1 Introduction

1.1 Overall challenges

Before discussing the current and potential benefits of information technology, we would like to review some of the overall challenges any construction business and project faces:

Business Challenges

It is a challenge to manage **scope, cost, schedule, and complexity** of projects concurrently. Projects are complex not only from the complexity of the built environment, but also from the multi-cultural, multi-location, multi-disciplinary, multi-organizational nature of construction projects. Although there is always room for improvement, cost and schedule challenges have been well documented and businesses have developed workable strategies to address these constraints. The most significant advance in the underlying logical models for mastering schedule has been the development of critical path logic and software and corresponding indices to support that greatly improves the tracking and control of cost and schedule (Fleming and Koppelman 1996). Complexity, *per se* is another matter. There is no comparable underlying logical model for measuring and managing complexity. History has had numerous examples of complex construction projects particularly when compared to the level of technology available at the time. However, the older the projects, the greater the likelihood that it took decades to complete them. In some cases, e.g. large European cathedrals, they took centuries to complete. This pace of construction assured that the process was linear which led to fewer opportunities for coordination mistakes. There is little question that construction projects today are more complex than in the past, but there is not yet general agreement as to how to measure the complexity in a way that yields useful management alternatives. We will return to this question again below.

IT challenges

Standardization: The WDI-CIFE 4D project experience (Fischer et al. 2001) is that it is difficult if not impossible to enforce standardization of tools in a design environment. The reason for this is simple. As design tools evolve, they are optimized for specific design tasks. The ability to perform these design tasks more effectively has clear benefits. However, this focus on single-dimension optimization of design tools can have severe drawbacks on information exchange and corresponding process efficiencies. The inability of project management tools and measurement techniques to quantify the benefits of accepting 'sub-optimal' design tools in exchange for more optimal data integration is one of the more challenging IT issues to be tackled during the next few years. As procurement and construction performance improves, the ability to quantify the benefits of standardized data exchange will improve. To keep the previously available design optimization, it is likely that the ability of these optimized design tools to exchange data in a variety of product model schemas will become the norm.

Security: Keeping design and project performance data secure over the life of a project without hindering the information flows necessary for productive work is still an unsolved problem given the business complexities noted above. Technologies such as peer-to-peer computing will continue to provide challenges to the maintenance of secure environments.

Sharing: Data must be shared to be useful in the multi-disciplinary, multi-phase context of construction projects. The challenge is to do so in a way that reflects the particular details of each project. This is the crucial part of managing collaboration. The grand unifying goal of a universally shared product model schema for every component of the AEC industry is not likely to become a reality for many years, if ever, although schemas like IFCs (Industry Foundation Classes) appear to offer enormous potential to come close (Yu et al. 1998). Our research groups have demonstrated IFC-based data sharing on a pilot construction project. Intermediate solutions such as aecXML can also provide effective solutions for the medium term, especially when the shared data does not include enormous geometric complexity. What will likely occur is that architecture and engineering design software will be able to exchange data across multiple product model schemas, independently of their native data structures.

Measurement challenges

The methodology for measuring **process transactions**, i.e., who communicates what to whom and when, is not well established. Control of design, procurement, and field operations are also typically organized in an ad-hoc manner, as appropriate for the needs of a specific project. Consequently, comparisons between projects are difficult. In principle, if the transaction is logged, that log and associated reply should serve as a proxy for the confirmed data transfer. In addition to the design requirements, specifications and building geometry, this log should include ordering, invoicing, RFIs, change directives, deficiency correction notices, etc. Many of these transactions are already seen as a key first step in supply chain management of the AEC industry. Understanding how the flow of this information should be integrated with project controls and design data will enable both the design data and the required materials to arrive on the job site at the right time and the right place. With the wider acceptance of project extranets, the benefits of understanding these transactions will be easier to capture.

Process simulation challenges

We lack the fundamental “theory” to enable truly **predictive simulations** that permit many more design iterations than possible today and shift re-work from the field to the computer. For example, the WDI-CIFE 4D team has developed a 4D software tool that allows interactive simulations of construction sequencing (Fischer et al. 2001). These simulations, while informative and useful are not truly predictive, since they cannot yet be auto-generated for more than one component at a time.

1.2 Benefits from IT

Many authors report the difficulties in measuring the benefits from IT in a consistent and replicable way (e.g., Lautanala et al. 1998). While the potential long-term benefits of IT are quite clear (reduced waste, more consistent and less variable processes, etc.), it is not clear how to get there, provide value, and be profitable all the way. A NIST study of 700 projects showed that:

- Greater use of IT correlates with better project performance.
- Owners and contractors realize meaningful benefits.
- There is a pronounced IT learning curve, but the benefits outweigh the risks.
- IT affects schedule compression beneficially.
- Overall project cost savings and construction cost savings of 4 % accrue due to increased use of IT.Howard et al. (1998) also report benefits from IT use. At an IAI meeting in Germany in 1998 Wolfgang Haas reported savings of 2 Billion DM per year just by improving the quality of DXF data. Haas speculated that the main reason for the savings is that work related to and caused by information exchange decreased by 50% in the receiving company.Enkovaara and Heikkonen reported potential savings of 7% in construction costs through efficient IT use. This estimation did not include any savings that could accrue from reducing errors with better information management.At the IAI meeting in Washington, DC, in April 1999, Thomas Liebich and Jeffrey Wix shared their study in several countries that showed that removal of information re-keying would enable savings of 16% in the construction costs. At a presentation to VERA board members at the Finnish Embassy in April 1999 in Washington, DC, Dana Smith from the US Department of Defence reported that the DOD spends US$ 40 Million per month on additional work because of the lack of information standards. Construction by the DOD makes up about 4% of the US market. Hence, information standards could lead to savings of US$ 12 Billion per year in the US alone. A study by the Electric Power Research Institute identified a critical path savings of 4 months from 48 month schedule for power plant in Korea by systematic use of a 4D model in construction planning (Virtual 2000). Lautanala et al (1998) estimate that full adoption of IT that is now on the horizon would lead to a net savings of about 6.5% in the Finnish construction industry. Participants at a workshop on the application and benefits of 3D and 4D modelling in May 1999 reported many benefits of 3D and 4D models. However, organizational, business, and contractual practices made it often difficult to reap these benefits on a consistent basis because the party in control of the information necessary to accrue a benefit is often different from the party actually accruing the benefit (Fischer 2000).

We have briefly summarized the reports above not only to point out the range of benefits that have been reported (some authors, e.g., Koskela and Vrijhoef (2000), conclude that IT has a detrimental impact), but also to show the anecdotal nature of these studies. A goal, if not the main goal, for the construction community in the next few years has to be to establish consistent measures, processes that can be measured consistently, and IT that makes it easy (free) for professionals to collect and analyse project performance measures.

2 Near term goals and benefits: "Stop the pain"

2.1 Near-term goals

The short term IT goals which characterize the AEC industry today might be best characterized as those which are focused on elimination of problems: "stopping the pain" of inefficiency, poor communication, and wastage. Figure 1 illustrates the productivity disparity that has grown between the discrete manufacturing industries and the construction industry. These differences are so large that they clearly imply a level of inefficiency in the construction industry that has been hidden or ignored or intentionally left in place.

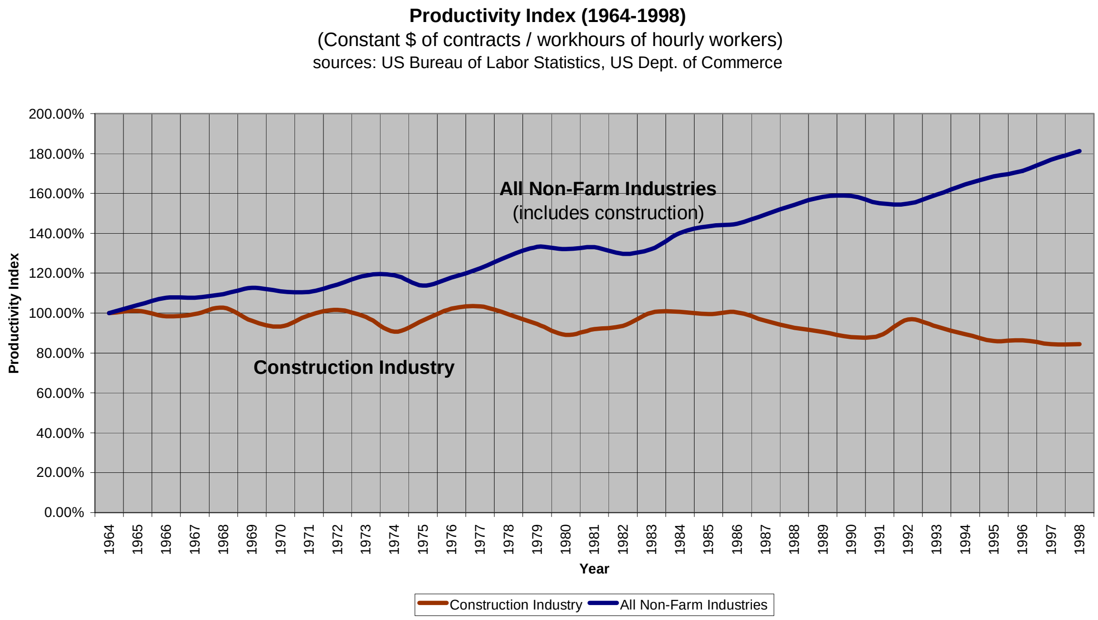

Figure 1. Productivity in the construction industry and all other non-farm manufacturing industries in the US. (Figure used with permission of Paul Teicholz, Professor (Emeritus), Stanford University)

The last point bears some evaluation because the nature of the contracting relationships and the sharing of risk between the various partners may provide one of them with a small, localized advantage or benefit. We believe it is for this structural reason, namely the systematic desire to avoid rather than share risk, that the construction industry is justly well known for its claims and claims settlements as the final determinant of a project's cost. Interestingly, this reputation has been earned largely in the past five decades. Therefore, a first goal is to identify the source of these inefficiencies and develop strategies to eliminate them.

Studies by the WDI-CIFE 4D project and in the organizations of the other authors have identified the main sources of inefficiencies, as reflected in the quantity of unbudgeted change orders. They are:

- discretionary design changes during construction,
- waiting for work,
- deficiency rework,
- unforeseen site conditions,
- untimely (late or early) procurement strategies,
- unnecessary movement of inventory, and
- poor coordination of design and specification.

These are reminiscent of the results demonstrated by Taichi Ohno (1988), who cited "overproduction, waiting, unnecessary transport, over-processing, inventories, unnecessary movement, and defective parts" as the principal causes of waste in his landmark study of Toyota. Hence, in the near term we suggest that firms pursue these goals:

- improve information availability
- improve decision making
- reduce impact of mistakes
- improve ability to respond to changing conditions

To address these concerns specific to the AEC industry, we believe the near term goals related to the deployment of IT should focus on improved **visualization**, improved **problem predictability** through improved **transactional tracking** and **quantification of results** from IT investment.

2.2 Near-term tools

Almost by definition, near term tools are those already available in the marketplace. The challenges of implementing those tools are principally organizational and financial. Most, but not all are software related. We address here only those tools that have the construction process as their primary focus. Tools for the construction process are intended to address the most common complaints (incompleteness, poor data exchange, not predictive) heard from practitioners about existing project management software tools.

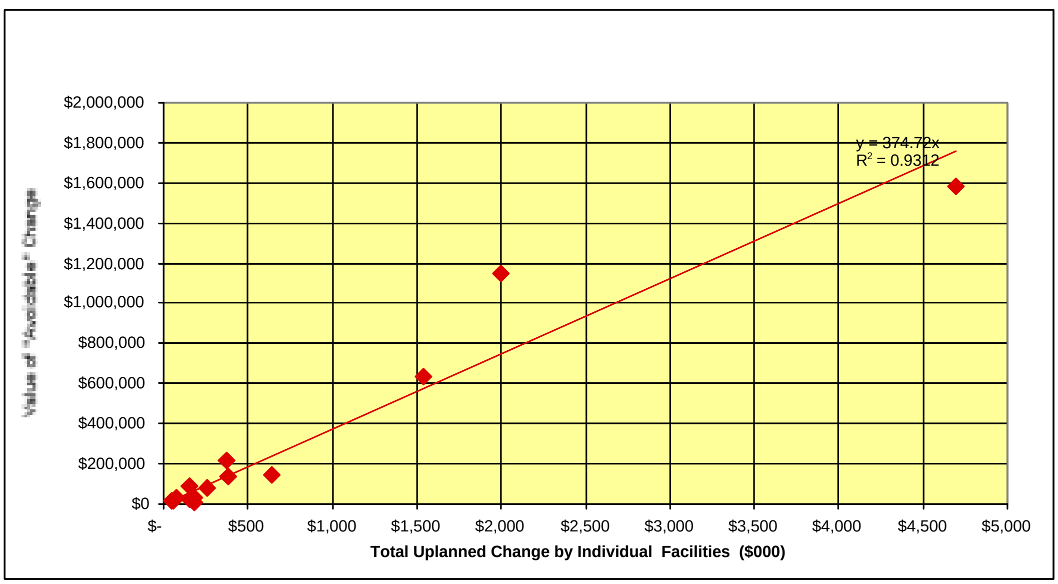

Figure 2. For a series of separate facilities, the chart shows the fraction of the unplanned changes that could have been discovered and avoided in a timely manner through 4D modeling. The chart shows that about 40% of the unplanned changes could have been eliminated through the application of 4D models. The quality of the design documentation was similar across the facilities, and the work was performed under comparable contractual conditions.

Visualization: Several studies and the authors' experience have shown substantial value from the adoption of 3D design tools alone. These tools do not only allow the rapid visualization of the built environment, they also enable the concurrent and subsequent use

of 4D for the construction planning and management. In essence, if 3D is the most accurate way to design the finished building, 4D is the most accurate way to design and visualize the process by which the buildings will be built. These 4D tools communicate a project design and schedule more effectively than 2D drawings and bar chart schedules. Figure 2 shows the results of a post construction analysis to estimate the potential savings that might have been realized from the systematic use of 4D tools during the construction process. The data are from multiple facilities in a large building program on the west coast of the US.
We expect that visualization techniques will provide methods to proof the design, logistics, assembly, lift and overall schedule plans. We expect that visualization tools will be used in the start of a design and through the process of coordinating people, machines, and components used to assemble structures. However, even though a project team can view the information from various vantage points and even fly or walk through it, it cannot yet interact with the 3D and 4D visualizations to explore design alternatives and to resolve design issues rapidly in a collaborative setting. It is the medium- and long-term potential for the widespread use of interactive tools of this type that holds the most promise for altering the productivity of the AEC industry.

"**Transactional" data collection**: Numerous collaborative extranet solutions are now starting to be widely adopted. Used properly, these extranet solutions can provide a wealth of data and allow users to clarify strategies for future supply chain management efforts. For example, we expect that the prompt delivery of information will support short-term efforts for controlling schedule and cost increases once a project is underway. We expect to better respond to changes or changing conditions. We expect that the impact of mistakes will be reduced. Transactional data alone can be used to support the type of pilot studies that will form the next generation of PM tools. For example, our work has shown that the time required to respond to information requests is a good proxy for the early assessment of staffing levels. Likewise, the variance around the time to respond is a reasonable proxy for the "completeness" of the design data. Increasing variance is a leading indicator of unresolved issues with the potential for change liability later in the project.

Pilot studies: If pilot studies in the construction industry have wider applicability to the companies performing them or to the industry as a whole, then these studies may well become an important strategic tool to evaluate the effectiveness of and justification for investments in IT. Figure 3 shows the rate of change as a function of the size of a given work package (data from the WDI-CIFE 4D project).
Pilot studies can be one of a cost-effective method for verifying lessons learned from other companies in the AEC industry or from related industries. Figure 3 provides quantitative support for the scalability of these pilot studies. Pilot studies in the electrical power industry have shown that:

- change orders cost five times the nominal value of the change approved by management,
- schedule impact is significant due to ripple effects,
- engineering in the field is much too late to be doing efficient business, and

- schedule compression requires integrated review and monitoring technologies.

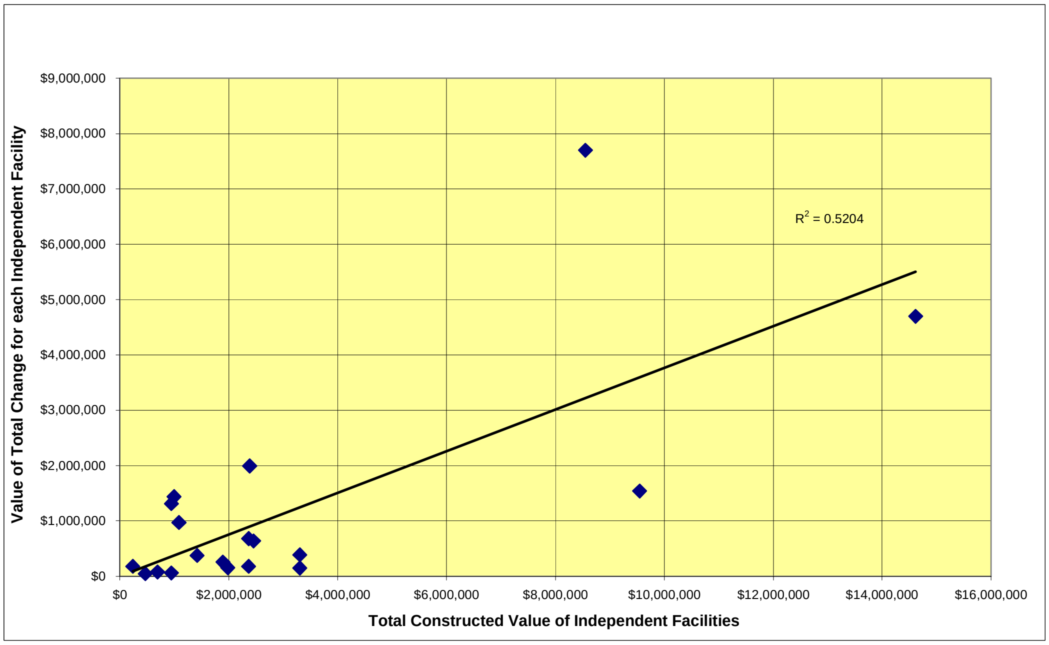

Figure 3. Dollar value of total change in construction projects with comparable level of design documentation and contractor performance.

2.3 Near term-metrics

Quality of design documentation: The ratio of drawings, or 3D objects to the dollar value of the work can be a rough measure of the quality of design documentation. These ratios, although imperfect, at least have the potential to allow inter-project comparisons. Meanwhile, research is currently in progress to define the underlying formal information models that may have the ability to provide an independent scale of geometric complexity.

Individual team task performance: This near-term metric is characterized by quantification of transactional data provided by project extranets. The assumption is that the 'perfect' project is a project with no unplanned, unbudgeted changes. In this 'perfect' condition the design documents are complete, the specifications consistent with the design, the materials available within the project timeline, etc. Deviations from the ideal can be tracked by the document trail during the process of construction management; i.e., memos, RFIs, change orders, deficiency correction notices, etc. The ratio of those as a function of the ongoing construction cost (by individual teams) can provide insight into the performance of the team.

Assembly complexity: Assembly complexity can be conveniently measured as the number of simultaneous activities occurring during a large construction project. 4D models could easily provide this information. Although most construction practitioners are aware that coordination is an expensive and important task, there is no standard method of measuring in advance how much coordination will be needed. Even though a metric like this is not a direct measure of the required coordination, it is still a useful first approximation that may be discarded when metrics that are more direct are found.

Design iterations: The experience of the discrete manufacturing sector clearly shows the benefits of increasing iterations in the design process. However, in the AEC industry, the most popular method for holding down soft costs (which produce the greatest number of iterations) is to minimize iterations by ‘freezing’ the design at a low number of iterations.

Request Response Time: The WDI-CIFE 4D team results have shown that for scopes of work with RFIs and shop drawing submittal approvals which have aged several standard deviations from the mean are disproportionately likely to result in major unplanned change. For this reason they are a good predictor to management of future problems. Fortunately, response time is easy to measure and easy to report with the current generation of project extranets.

2.4 Getting the players on board

It is a truism to say that IT tools will be adopted when the profitability of doing so is evident. The more difficult question is “whose profitability’. Since so many of the promised benefits are captured at the whole project level, it seems to us that the place to look for adopters will be large vertically integrated organizations who design, build, own and operate complex facilities. They are in the best position to capture those early benefits. Not surprisingly, large multinational manufacturing organizations with a built-in incentive for speeding up construction of specialty manufacturing facilities are at the top of the list in adoption and study of these issues. Right behind them are power and chemical process plants, airports and some civil infrastructure projects.

3 Medium Term: Strategize existing processes better

3.1 Medium-term goals

Once we have some transaction or process data that has been collected more consistently than is typical today we will have the basis to redesign the existing processes to create process synergies, improve drawing and information coordination, improve workflow, and justify, target, and prioritize investments in IT. The goal is to reduce the number of redundant tasks and to bring the necessary stakeholders on board at the right time to enable the generation of project information that can be shared electronically with others in the same phase and throughout the future phases of a project.

3.2 Medium-term tools

We foresee that the following tools will play a significant role in strategizing existing processes better. Some of these tools are already in use on projects today. We believe that significant benefits will accrue when these tools are used concurrently on projects.

- Work packaging and structuring
- Look-ahead schedules
- Transportable data
- iRoom

Work packing will enable organizations to break up the scope of a project to align risks and responsibilities better. Visualizing the break-up of the project scope into various contractual 'chunks' in the context of 3D models and seeing the progression of these contractual 'chunks' over time in the 4D model will likely be an important tool for the design, communication, and management of the work breakdown structure. Look-ahead schedules will make the work assignments clear at a level of detail that makes it easy to measure whether an assignment has been completed or not (Ballard and Howell 1995. The technologies discussed in section 2 should help establish whether the original assignment was indeed a workable assignment.

Data from architectural 3D CAD packages is quickly becoming more accessible and transportable. Many 3D packages already have an 'IFC out' method to exchange the information of 3D model data. In the medium term, we will see some data integration via aecXML, IFC, IFC-xml, etc. On a project at the Helsinki University of Technology (HUT) the architect, mechanical designer, general contractor, and owner are using IFC-based product models to share project information between the software applications of these organizations. Figure 4 shows who generates parts of this model and who consumes the model data.

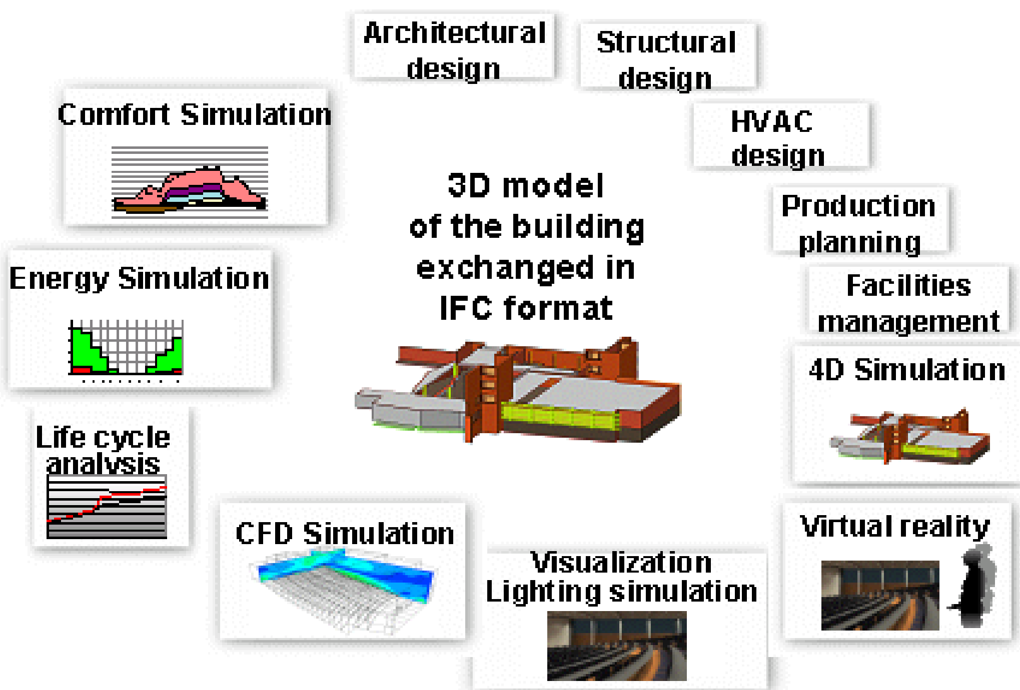

Figure 4. Exchange and use of IFC-based 3D product model for multiple project tasks by multiple firms on HUT project.

Several years ago YIT Corporation embarked on an ambitious R&D program to base their estimating and production planning software on product models. YIT management had concluded that documents transfer information poorly between project phases because they do not make design information amenable for direct interpretation by other computer programs. In recent years, YIT has converted their estimating and production planning software (COVE) to be compatible with the Industry Foundation Classes (IFC R2.0). The goal is to provide decision support for YIT's customers by giving them, in the briefing phase, reliable estimates for income, costs, and the hand over date, as well as data about the project's economy over its life cycle (Laitinen 1998). YIT has seen the following results from their product model-based cost estimating and production planning systems:

- 80% reduction in time to generate cost estimates (including model analysis and creation of alternatives),
- cost estimation accuracy of +/-3%, and
- quick generation of visualizations from the COVE model including studies of alternative solutions and their impact.

Including all the effects of a product-model-based system like COVE, the approach promises savings of up to 10-15 percent of the total building costs. When compared to the typical 4 to 7% profit of construction companies the need for these model-based systems becomes obvious. YIT's COVE (Cost and Value Engineering) solution, built with technology by Solibri, Inc., integrates with the proprietary cost estimation and production planning systems of YIT. COVE's features include transforming ArchiCAD object models into intelligent product model elements with YIT's construction methods and production knowledge. Virtual reality views of the product model make communication with project participants efficient. Design 'spell checking' (Figure 5) and 4D analysis of production schedules enable YIT project are further advanced features of YIT's production management and customer support environment.

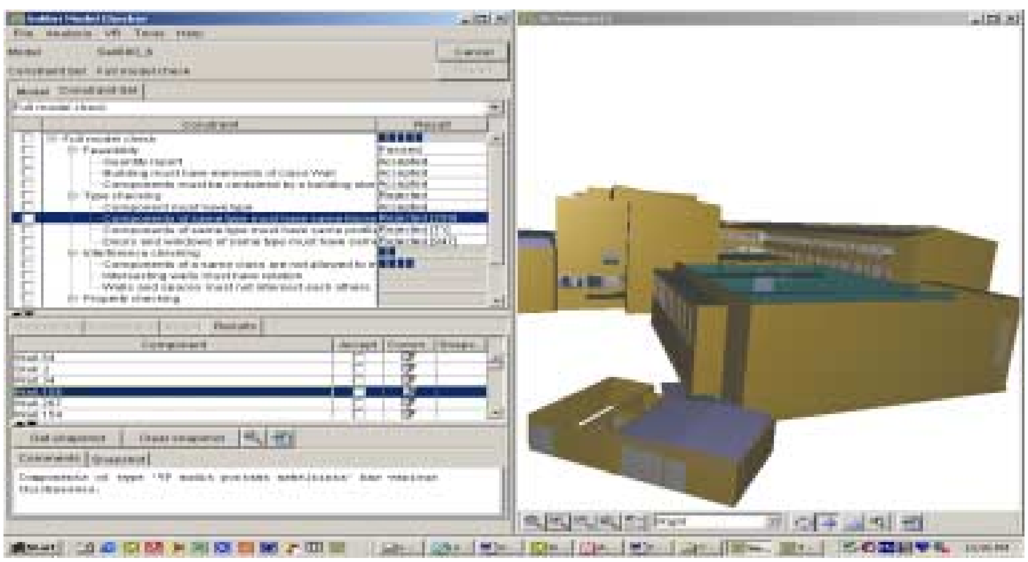

Figure 5. Example of design 'spell check' analysis in COVE.

Likewise, Olof Granlund Oy, has made all its mechanical design and analysis tools IFC compatible. Granlund routinely builds 3D building models in the IFC format if they do not already receive an IFC-based 3D model from the architect. Granlund's IFC compliant building services design tools import these models directly, which saves about 40 working hours in data entry on every project. The design tools then perform the life cycle calculations for all project design alternatives (e.g., Figure 6). Typically, time schedules do not normally allow the generation of all the simulations and calculations required to make the decisions that lead economic life cycle solutions. By using IFC-based 3D models, alternatives can be created and studied quickly without delaying the project schedule. Granlund's experience shows that the savings potential through life cycle cost comparisons is typically in the 5 to 25 % range of a project's life cycle costs. In addition the environmental impact of the mechanical systems can also be minimized through life-cycle modeling and comparison of alternatives.

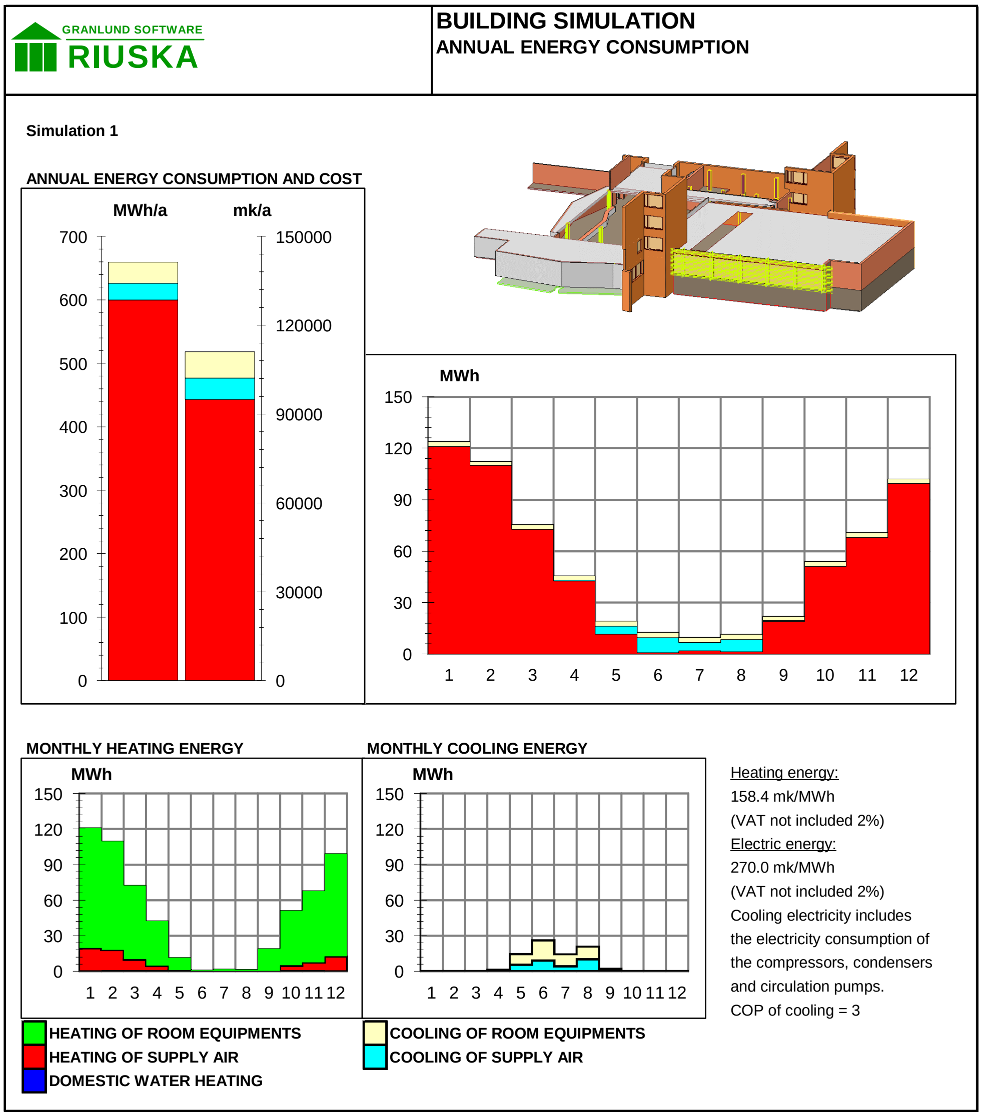

Figure 6. Example of an energy simulation for a building based on an IFC-based 3D model.

The iRoom (Interactive Workspace) is a research project in the Department of Computer Science at Stanford University (Figure 7). The iRoom allows users to connect any number and types of information devices (interactive touch-screens, desktops, laptops, PDAs (personal digital assistants), cameras, scanners, etc. to each other via the iRoom software infrastructure (Fox et al. 2000). As a result, users can move around and connect information across the information devices that are part of a particular session. The iRoom supports the multi-user, multi-discipline interaction with project information that is necessary (but not currently supported) for decision making on construction projects. It uses simple transaction- or message-based data integration.

Figure 7. Interactive Workspace consisting of several interactive smartboards, a table display, and other information devices such as laptops, PDAs, cameras, scanners, etc.

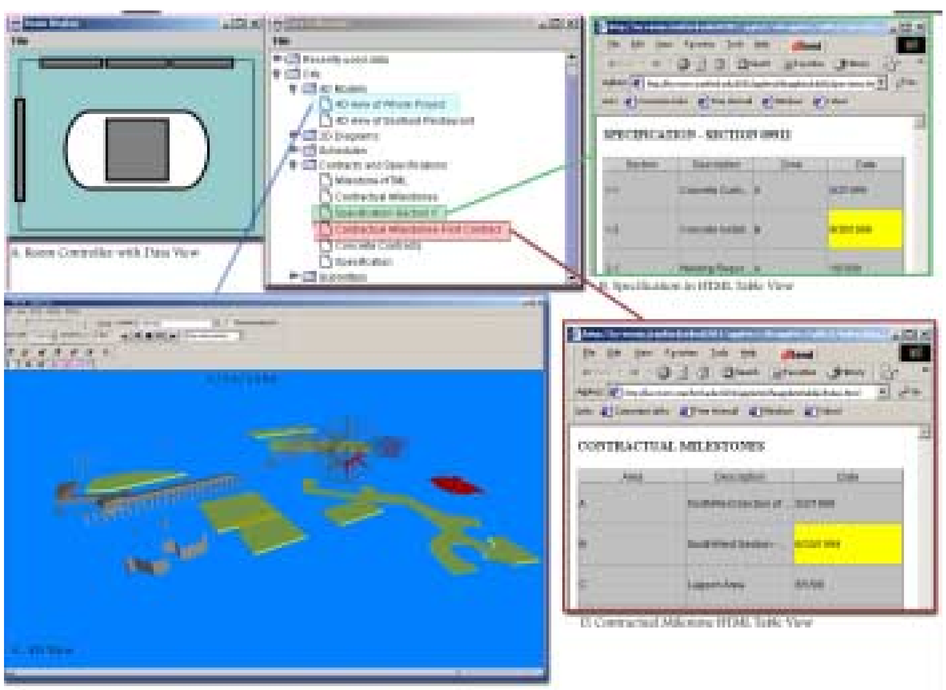

Figure 8: Important relationships and corresponding information sharing between documents on a construction project.

For example, if a date is selected in a particular document view (application) the other views that contain the date jump to that date or highlight items related to that date (Figure 8 (right hand boxes)). The selection of a milestone date in the contract document in the lower right window triggers the highlighting of related (same date) items in a specification document (upper right). It also adjusts the view in the 4D CAD window

(lower left) to the same date, i.e., the 4D application shows the planned state of the project (what has been built, what is being worked on) at the selected milestone date. The upper left part of the figure shows the room controller and a list of available documents. The room controller allows users to drag a view and service to a particular device. Note that the figure shows the various views in close proximity. In the interactive workspace, each view can be on a separate information device that is connected to the workspace.
As mentioned, examples can be found where some of these tools have been used beneficially in isolation. We anticipate far greater benefits when the processes, organization, information generation, and use are aligned and support these tools and vice versa.

4 Long Term: Dramatically improve productivity throughout the supply chain with a holistic approach to operations

4.1 Long-term goals

In the long-term, the focus will increasingly be on providing services for the life-cycle of facilities, considering explicitly life-cycle tradeoffs in decisions in all project phases. We suggest the following goals:

- Enable collaboration of entire chain of performers without re-entry of data
- Substantial reduction (or near elimination) of rework
- Substantial improvement in project cycle time
- Ability to handle increasingly complex projects
- Vastly reduce risk
- Greatly increase project value

Our thesis with respect to total cycle time reduction is that design information must be able to be communicated across discipline and contractual boundaries and presented in a manner that best suits the using organization. This concept implies a system capable of representing design and construction information in a flexible schema that provides links to the source material such that design and construction conflicts are swiftly resolved.

4.2 Long-term tools and concepts

We expect that the development of long term improvements will principally be driven by the emergence of standard means of communicating design attributes such that quantity-specific items are not only shown in CAD models, but also schedule models, procurement systems, and site work management systems. Shared information will be available to all members of the design, procurement, construction, and installation team. The focus will be on practices and processes and on the creation of systems and processes that produce reproducible results.
Specifically, the following toolset will be part of designers', constructors', and facility managers' toolset in the future:

- Interoperable data sets
- Interconnection of team members

- Software and data standards
- Collaborative Engineering Architectures (Design 2000)

This toolset will support set-based design (Sauter et al. 1999), which will make it possible to delay decisions to the last responsible moment (the term 'last responsible moment' was coined by Bob Lane from the British Airport Authority) without impacting cost, schedule, and quality performance negatively. This toolset will also eliminate many of the shop drawings because direct fabrication from 3D models will be common-place (it is already practiced on several projects today mainly by steel fabricators and mechanical and piping firms (Staub-French and Fischer 2001).

Design will become one whole process, encompassing considerations from all project life cycle phases (e.g., a design is complete when it can be built. This will support better alignment of design, construction, operations, and facility management because customer values drive the project production system. The alignment of production and design review times will remove waste. Advanced 4D simulations (Akbas and Fischer 1999) will establish 'takt' times and enable more efficient space utilization even for one-off, complex facilities, which in turn creates the flow needed for reliable and increased production volume. It will become possible to combine bottom up continuous improvement with top down policy setting to better utilize knowledge and production capabilities in supply chains.

4.3 Closing thoughts

The generation of project and construction management personnel that built the bulk of the projects in the 1960's and 1970's will have retired by 2010. The lack of senior experienced personnel coupled with the tightly scripted construction schedule for future projects tied to the promise of modest capital costs requires a better system for assessing project performance and adjusting project resources to meet the schedule despite expected upsets caused by weather, labor factors, design changes and late arriving materials and equipment. Innovative methods for assessing project performance and making predictions of project outcomes will be required. In effect, project simulation is needed for not just the details of coordinating the sequencing of the construction work, but to also provide examination of alternatives once changes are presented. These tools will focus on change management methods and provide the kind of feedback concerning cost and schedule impact that is lacking in today's project management systems.

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