POTENTIAL EFFICIENCY GAINS IN THE CONSTRUCTION INDUSTRY FROM THE PROPER USE OF INFORMATION TECHNOLOGY

by

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SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Submitted to the Department of Civil and Environmental Engineering
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ABSTRACT

For many years, technological advances and new software have altered the face of the engineering design sector. Design companies have realized incredible efficiency gains and cost savings due to these improvements, but the construction sector has not been able to do the same. Unlike design firms, contractor businesses as a whole have not embraced IT advancements and taken steps to implement them across all types of construction projects in the most efficient and effective manner possible. Because of this half-hearted attitude towards technological improvements, the same efficiency gains and cost savings found in the design sector have not been attained in the construction sector.

The thesis examines different types of IT advancements that have the potential to seriously benefit the construction sector, including electronic document management, 3D modeling, construction sequencing, and laser scanning. Several surveys performed by other engineers and academics interested in the field of information technology in the engineering and construction sector will be examined, and the results of these will provide the basis for discussion regarding the current state of IT saturation in the construction sector as well as its overall effectiveness in providing tangible benefits to users. In addition, this thesis also examines possible reasons for why these benefits are not being attained and offers some ideas and strategies that may improve the implementation of IT advancements in the construction industry.

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Thanks to Mom and Dad for footing the bill, thank you Jerry Connor for teaching me what a tuned mass damper is, thanks to Lisa O'Donnell for helping me jump-start what can only be described as my "super great career," thanks to (most of) my teachers and professors for passing me, thanks to the M.Eng classmates and the rest of my friends in Boston for sucking my life away, thanks to Kyle, Summer, and Tammy for constantly reminding me that I actually had a thesis to write before graduating, and thank you Leslie Robinson for not thanking me in your acknowledgements.

And thank you to diet soda and cigarettes for being invented. Without you, I could have never finished this really big book report.

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1.0 INTRODUCTION

For many years, technological advances and new software have altered the face of the engineering design sector. Design companies have realized incredible efficiency gains and cost savings due to these improvements; however, the construction sector has not been able to do the same. Unlike design firms, contractor businesses as a whole have not embraced IT advancements and taken steps to implement them across all types of construction projects in the most efficient and effective manner possible. Because of this half-hearted attitude towards technological improvements, the same efficiency gains and cost savings found in the design sector have not been attained in the construction sector.

With the proper implementation of information technology, companies in the construction industry have the potential to lower project costs, shorten schedules, and streamline the overall coordination between managers, suppliers, and laborers. Additionally, more and more problems will undoubtedly result from the growing technological rift between design teams and contractors if the construction industry continues to be unwilling to grasp new standards in software, construction documents, and general methods of doing business. Those contractors who are willing to keep up-to-date with the design engineers will reap the benefits associated with advancements in information technology, but those who refuse to learn and adapt to these new standards will have trouble remaining competitive. Therefore, not only will IT use in the construction sector provide efficiency benefits for day-to-day work, but it also appears that implementation and adaptation to new technology is the only method to remain competitive in an ever-growing and constantly changing capitalist market.

The subsequent paper will discuss the following:

- several types of IT developments that have been or are becoming available to the construction industry, specifically electronic document management, 3D modeling, construction sequencing, and laser scanning
- the potential benefits offered by these technologies
- reasons for why these benefits are not being truly attained
- ideas or strategies that may improve the implementation of IT advancements in the construction industry

Several surveys performed by other engineers and academics interested in the field of information technology in the engineering and construction sector will be examined; the results of these will provide the basis for discussion regarding the current state of IT saturation in the construction sector as well as its overall effectiveness in providing tangible benefits to users. Although this background information and overall discussion is essential in understanding the importance of IT, the key aim of this thesis is to better grasp the reasons behind the lag of IT implementation in the industry as well as provide some basic ideas regarding what can be done to improve the situation.

2.0 TYPES OF IT DEVELOPMENTS AVAILABLE TO THE CONSTRUCTION INDUSTRY

The most important feature of technology-based engineering solutions is the ability to allow users to share and manage large amounts of constantly changing information. This is incredibly vital in the construction industry because of its very fragmented nature; multi-disciplinary information exchange between design engineers, contractors, subcontractors, and suppliers is high in volume and is often a source of project inefficiency and slow-down. Technologies such as Electronic Document Management, 3D and 4D modeling, and many others have the potential to create large efficiency gains in the field of construction.

2.1 Electronic Document Management (EDM)

"Going paperless" has long been a dream of many design project managers due to the potentially immense waste of resources as well as major difficulty in keeping outdated paper copies from being used over the most current ones. Many difficulties can arise from the improper management of contract documents, including delays, mistakes, and expensive rework.

A popular solution to these difficulties in the design sector has been usage of the internet and/or intranet for document management, a solution which has also begun to enjoy popularity among construction projects. In recent years, the internet has become the single-handed most valuable tool in information exchange and management. The pervasion of the internet throughout the globe coupled with the widespread availability of personal computers provides the necessary infrastructure for efficient computer-aided document management.

The evolution of contract document management has progressed from hand-delivered paper copies to digital copies distributed via e-mail or on CD-ROM. The most recent trend has been Electronic Document Management (EDM), a system consisting of a private network that uses internet protocols to transmit information. This type of system is typically accessible only by authorized users and utilizes a central database with a complete collection of all project-related documents. All these project documents are stored on a single server, and the user interface can be as simple as an FTP (file transfer protocol) site or as complex and user friendly as a web page complete with a search engine. Rising popularity of this type of document management has sparked the development of third-party service providers that offer off-the-shelf systems with customization for firms interested in outsourcing their needs. The setup, implementation, operation, and maintenance of these systems require minimal technical, financial, and human resources even with in-house development but can easily provide a boost in overall project productivity. Figure 2.1 below is a summary of the evolution of contract document management and transfer. It shows the progression of document transfer from:

1. Courier service for the transfer of paper documents
2. Electronic files transferred on diskettes
3. Electronic file transfer through e-mail attachments
4. Electronic data management through server technology and the internet

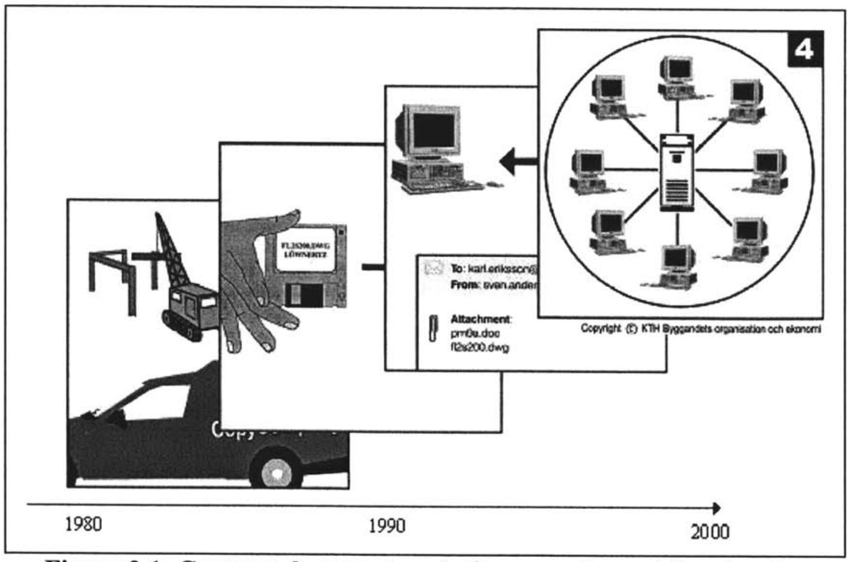


Figure 2.1: Contract document evolution over the past few decades

The simplest EDM system can consist of something as basic as a folder hierarchy system with a set of folders and subfolders containing different project information. Users can login to a password-protected website to access these folders and the documents within them and can edit, upload, or download whatever files they have access rights to. The figure below represents a screen shot of this type of EDM system.

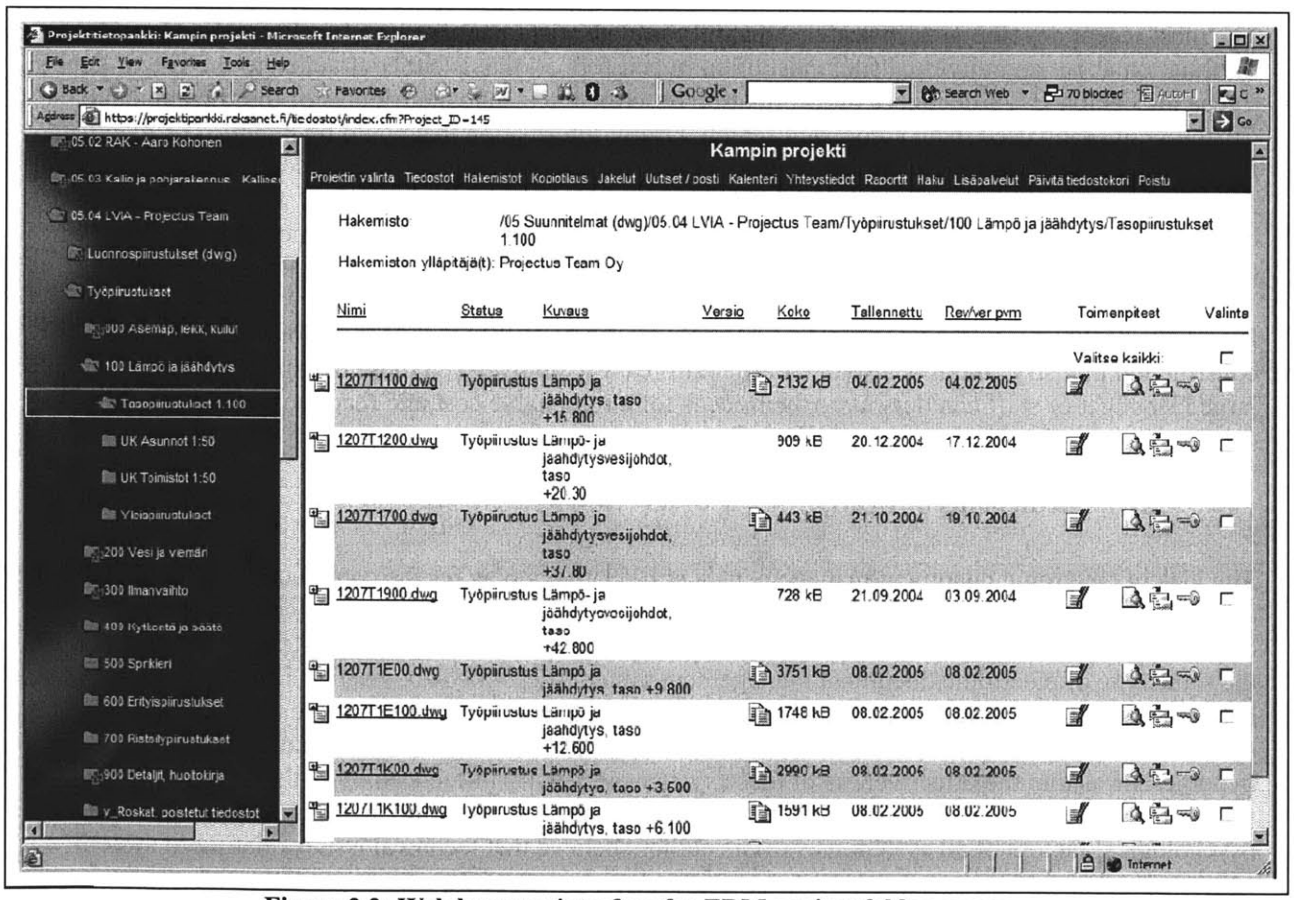


Figure 2.2: Web browser interface for EDM project folder access

The screen shot is from a web interface created by a third-party service provider, the Finnish Raksanet (www.raksanet.fi). The hierarchical folder structure is shown on the left-hand side of the screen, and the main portion of the screen depicts the different drawing files accessible in the selected folder. Next to each of the drawing file names is a brief content description, some information about the revision history, file size, etc. This folder structure is typically how construction professionals have traditionally organized and archived paper documents.

Often, these file management systems have more robust features included to enhance user functionality. A list of features found in most systems can be found below:

- A main retrieval mechanism based on either hierarchical folders or metadata
- Handling of revisions and change management
- Viewing of CAD files or other visualization programs using special purpose software

A retrieval system based on a hierarchical folder system can sometimes be hard to use if an individual is not familiar with the structure. Problems can arise from having a folder structure that is either too strict or too loose. Strict folder structures, if imposed on all other project parties, may force others to conform to an organizational system they are not comfortable with, and very loose folder structures which allow the users to create a folder structure of their own may cause even more problems with standardization and retrieval of documents. Without a proper method of retrieving documents, files and drawings may be just as hard to find as they would be on a shelf or in a pile. Therefore, systems with search capability are often very appealing from an efficiency and usability standpoint.

The most recent development in search capability is a metadata-based search function. Metadata is information about an individual file, most often in text format, that is either attached to the file or kept in a separate database. These pieces of information describe the essential attributes of the file and have the capability of being used in an automated search. Useful information that could be included as metadata for construction documents includes such things as when the document was created and/or last modified, what engineering discipline the document falls under, the author of the document, what part of the building it describes, etc. Recent efforts have been made to create a standard for metadata so that compatibility issues do not pose as big of a problem as they presently may.

Electronic document management is one of the less technically vigorous IT solutions available to the construction industry, and it is also one of the most easy to apply. Even those construction firms without a large IT budget or staff can outsource their needs for a reasonable cost and reap the benefits.

2.1.1 The Benefits of EDM

The idea of electronic document management is still relatively new for the construction industry, and its optimal method of use has yet to be discovered. In 2005, Pollaphat Nitithamyong and Miroslaw Skibniewski conducted an empirical study on web-based project management systems, another term for the same type of electronic document management systems described above. The aim of the study was to better understand the potential factors that may influence the performance of these types of management systems as well as potential measures that can be used to assess system performance. Their initial hypothesis was that the effectiveness of these systems is heavily influenced by both the state of readiness for implementation of an electronic document management system within an organization as well as psychological factors of all system users. The authors believe that technical issues relating to system operation and performance are sometimes too heavily emphasized, thereby overshadowing the factors more related to the people and individuals using the system. The study was conducted through a questionnaire distributed to both scholars and industry professionals working in the United States as well as international organizations with practical experience with document management applications. The demographics of the pooled individuals with respect to their roles and proficiencies are shown in the figure below:

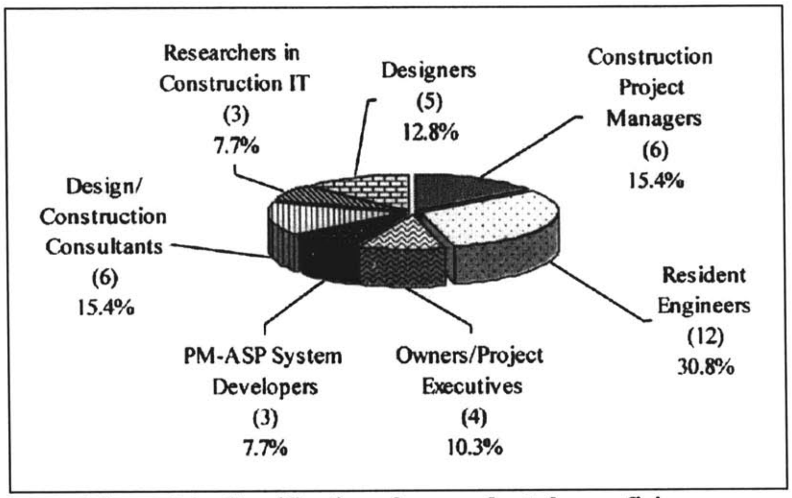


Figure 2.3: Classification of respondents by proficiency

A wide range of job proficiencies was polled and included the following: construction management personnel (owners, project managers, designers, engineers, construction managers, and design/construction consultants), application developers (system managers and software consultants), and researchers in the field of construction information technology.

The survey contained four sections collecting the following information:

- general information about the respondents
- opinions on the factors that influence the success or failure of electronic document management systems
- comments on potential performance measures and assessment of the degree of relevance of each measure
- open-ended questions asking for suggestions

The average number of years of experience in the construction industry of each respondent was 14 years, and the average number of years of experience for IT applications in construction was 7 years. The figure below depicts the authors' initial success/failure model and what factors affected the performance of electronic project management systems.

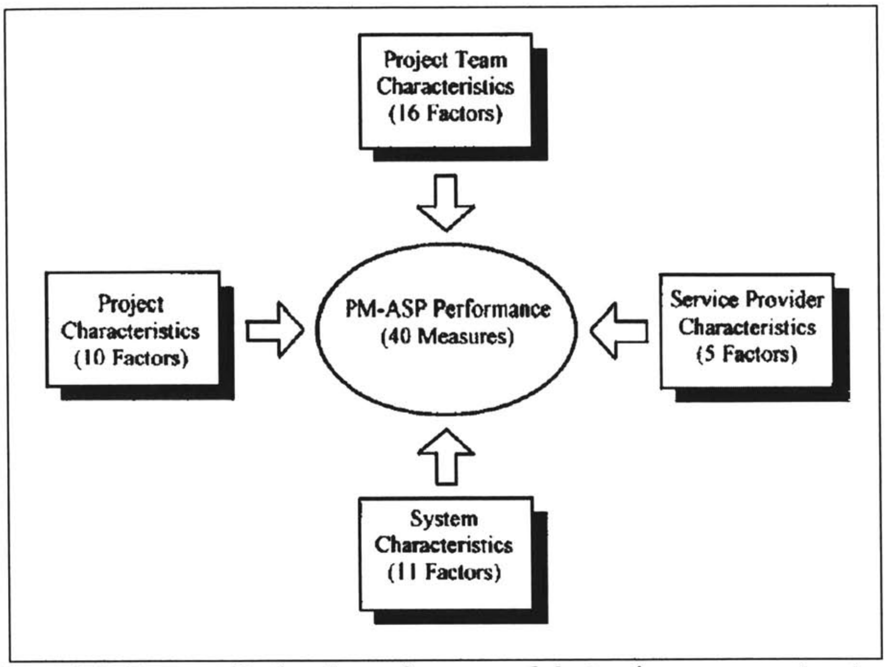


Figure 2.4: Factors affecting the performance of electronic management systems

Nitithamyong and Skibniewski believe that project team characteristics, system characteristics, project characteristics, and system service provider characteristics can influence the performance of an electronic management system. The two authors also created a list of performance measures for assessing the benefits of these systems; the top five benefits from using electronic document management rated by respondents within the United States were the following:

1. Enhances coordination among team members
2. Facilitates document transfer and handling
3. Reduces bottlenecks in communications
4. Reduces number of claims
5. Enhances organization of updated records

The most beneficial overall improvement achieved with electronic document is a more seamless communication between different team members as well as between companies. The EDM is a central system that streamlines all document transfer through one server and creates a single place where all the most updated documents can be found. The coordination between the contractor and the design team can often be a large manpower drain over the length of the project, and any measures that lessen those resource strains should be considered.

These improvements to performance can significantly enhance project efficiency and lower costs for contractors. It is hard to quantify the exact level of time and cost savings because the benefits are project specific and vary greatly from company to company depending on the level of IT sophistication, but it can be concluded with reasonable confidence that these benefits produce time and cost savings through the subsequent efficiency improvements.

2.1.2 General Attitudes towards the Use of EDM

Mathias Hjelt and Bo-Christer Björk from the Swedish School of Economics and Business Administration in Helsinki, Finland conducted a study on a large-scale project that explored attitudes toward EDM across various segments of the building team (architects, designers, contractors, project managers, and facility end users) on an individual level. The project on which the study was conducted was the Kamppi Center in Helsinki, a transformation of an open-air bus station into a complex underground bus terminal with the following components:

- over 1,700 departures per day
- a cargo center handling approximately 10,000 parcels per day
- 5,700 square meters of residential apartments
- 12,500 square meters of office space
- a 37,000-square meter shopping center
- an underground parking facility

The Raksanet software briefly mentioned above was the document management system chosen for implementation, a system that was familiar to some project team members, most importantly the contractor. Additionally, the software developers behind Raksanet have proven to be very sensitive to the suggestions for improvement put forward by users and have been known to implement new features and improvements on very short notice.

For the Kamppi Center project, approximately 1,700 folders containing 16,000 documents were accessed by 334 individual users over the course of the project. In addition to the standard EDM system features, an automatic distribution of paper copies was set up as well due to the demand for certain parties insisting on easy access to paper rather than only electronic documents. A system feature was created that allowed for the creation of distribution lists for each document produced. When each document is stored or updated in any folder containing a distribution list, the system automatically orders a predefined set of paper copies to be sent to the corresponding recipient list. Thus, even though this particular project utilized EDM, there were still remnants of traditional paper copy distribution; this was primarily to ease the discomfort and dissipate resistance amongst those individuals who were not as familiar with the EDM process. The benefits associated with lessening of paper copies is a key benefit of EDM, and in the case of this project, those benefits could not be truly realized.

The empirical study carried out by Hjelt and Björk involved two methods of obtaining information: an online survey and questionnaire distributed to a large number of users and semi-structured interviews with a smaller group of individuals. The results of the questionnaire are outlined below and were based on mostly quantitative questions asking the user to rate his or her level of agreement with various statements using a four-point Likert scale (agree completely, tend to agree, tend to disagree, disagree completely).

The general conclusions reached by Hjelt and Björk were that the usage of EDM was becoming more widespread and that professionals who have used these systems for some time are becoming much more dependent on them as the primary form of document and file transfer. Additionally, they observed that individuals who assume different project roles do not look at the system in the same way. Contractors and subcontractors seem to be the most skeptical of the benefits of EDM; they are also the user group with the least experience utilizing such systems. The figure below shows the overall skepticism of different user groups.

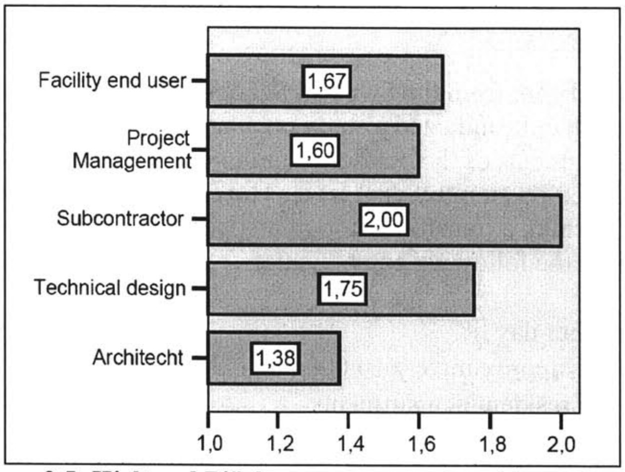


Figure 2.5: Hjelt and Björk survey – user skepticism by group

The authors believe that the main challenges in making EDM more efficient lie in the psychological factors of the users who are resisting the switchover to this type of document management and that this "mental resistance" differs amongst the various user groups, each needing distinct ways of being dealt with.

When asked if the company or organization each individual worked for could have done as well without the EDM system, the following results were obtained:

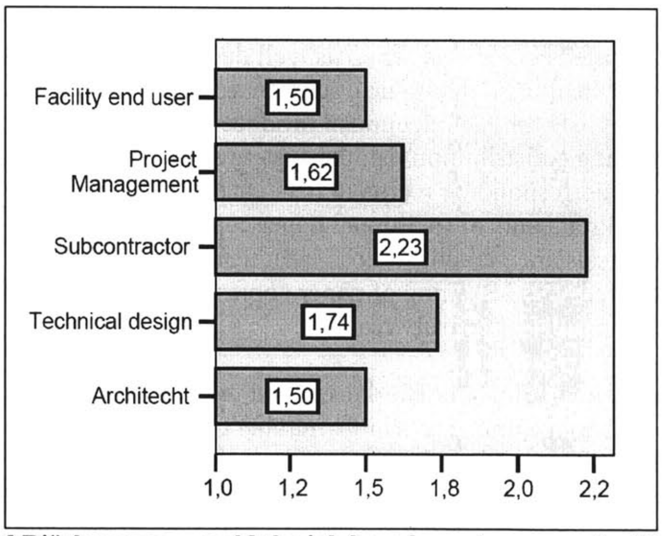


Figure 2.6: Hjelt and Björk survey – could the job have been done as well without the use of EDM

The subcontractor group was most convinced that the project tasks could have been performed just as easily or even easier without the use of electronic document management. Most other groups were far less convinced of this. One critical comment regarding the benefits of using EDM stated: "I do endorse the use of email and digital transfer of drawings, but this kind of project-wide document management is slow and cumbersome. No one has time to read all the reports flowing in from Raksanet." As mentioned above, the mental resistance of the contractor group is much more resilient than in other groups.

One of the most important aspects of effective EDM usage is that the individuals using the system are confident that the relevant documents are available through this system and that the contents are up-to-date. If users do not believe that this is possible, they will stop using the EDM and revert to e-mail communication or paper documentation. The study by Hjelt and Björk revealed that approximately 80% of the users agreed or tended to agree that they were confident the latest versions of drawings and documents were available in the EDM. However, there were some user comments that indicated a relative degree of doubt in whether or not the latest files were available:

- "It worked great, but updates were sometimes late for some drawings. In urgent situations we had to call the designers directly. This is understandable when a drawing needs to be updated often."
- "I think EDM is a great tool if everyone keeps the information up to date."
- "As a concept, EDM use is OK, but there's always a slight doubt whether the latest files have already been uploaded. Naturally, EDM works better in smaller projects. In a project of this size, there's bound to be problems with file management."
- "It's always a good idea to check with the designers whether the latest revisions are available in the EDM."

The overall results of this study suggest that although the architectural and design engineering professions have become very familiar and comfortable with electronic document management, the construction industry has still not embraced the technology with the same amount of enthusiasm, and some individuals who have been exposed to EDM still prefer older methods of document management and transfer. This study clearly delineates the important role of psychological factors in the IT lag within the construction industry. Reasons behind this psychological resistance will be outlined in a later section.

2.2 3D Modeling and Building Information Models (BIM)

Another IT development that has gained popularity in recent years is computer modeling in the third and fourth dimensions. These product models have the ability to generate reliable and quick cost estimates, construction schedules, and other important information such as indoor comfort designs, energy analyses, environmental reports, and life cycle cost studies from one information source. Most importantly, however, these computer models allow 3-dimensional visualization of construction projects so that clients, design engineers, and contractors can perform virtual walk-throughs, view realistic renderings of buildings before actual construction, and even examine construction sequences in 4-dimensional animations.

Several software programs have been developed expressly for the purpose of 3-dimensional modeling of buildings, including Graphisoft ArchiCAD and Nemetschek VectorWorks ARCHITECT, two relatively popular programs that are used widely throughout the engineering and construction industry. Rising popularity of 3 and 4D modeling has also prompted several companies and IT consultants to develop applications on top of various platforms that expand the capability of widely-used design software such as AutoCAD (Autodesk Architectural Desktop and Revit), Microstation (Bentley Architecture), and Solidworks. There are also software programs solely developed to general product modeling such as CATIA, although programs solely dedicated to building information modeling (BIM) such as those created by Autodesk and Bentley will be focused on in the following section since these programs' applicability to construction projects is more apparent.

These building information modeling (BIM) programs allow the user to create a virtual 3-dimensional building model with necessary architectural and construction-related information attached to it. In addition, the programs have the capability of producing standard construction documents that are similar to those created by 2-dimensional programs or standard drafting methods but at a much more efficient pace and with a greater amount of accuracy and detailed information (quantities, materials, etc.).

These software programs are generally categorized into two groups:

- Unidirectional editing with a multi-file database of information
- Bidirectional editing utilizing a single-file database or a multi-file, multi-database management system

Unidirectional editing implies that manipulating file information or extracted views will not automatically change the model or any other views; information is primarily kept in separate document files that are linked to the model, but changes to this information will not alter the model. The figure below is a screen shot from Autodesk's Architectural Desktop program, a unidirectional system.

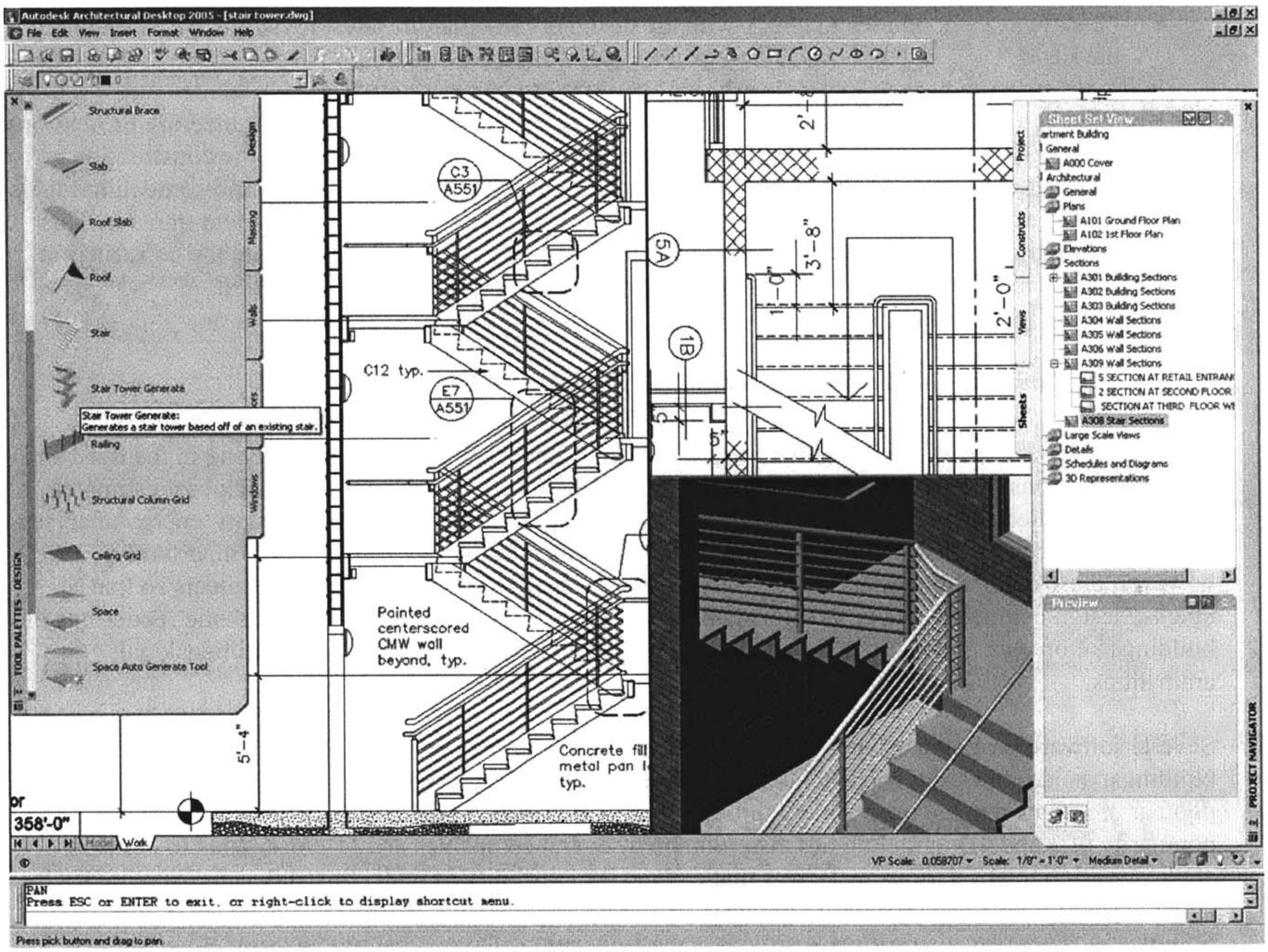


Figure 2.7: Architectural Desktop is a platform which operates on top of AutoCAD

All information is saved and located in separate .DWG drawing files which contain information on subdivided units such as doors, walls, or stairs. These files are linked together through a programmed x-ref system called the Project Navigator, which allows interaction with the overall program and model. As in all unidirectional systems, changes to views do not change the model itself, but changes to the models can be expressed in all views as long as each view is refreshed and saved.

Architectural Desktop is one of the most widely used software programs because it is essentially an enhanced version of AutoCAD and works largely with the native .DWG format that is universal throughout the engineering industry. Construction document production can be streamlined and greatly improved with the aid of software such as Architectural Desktop.

With bidirectional editing, any changes to a specific piece of information, to an extracted view, or to the model itself will affect the model as well as other linked information or extracted views. Bidirectional editing capabilities depend on a single file that manages the permanent interrelationships between all applicable project information, such as all related models, views, sheets, schedules, etc. In some cases, bidirectional editing can be achieved with a database management system that handles relationships between files and databases in an acceptable and efficient manner. Bentley Architecture is a software program that offers bidirectional capabilities as well as potential integration with multiple engineering analysis programs. A screen shot from Bentley Architecture is shown below.

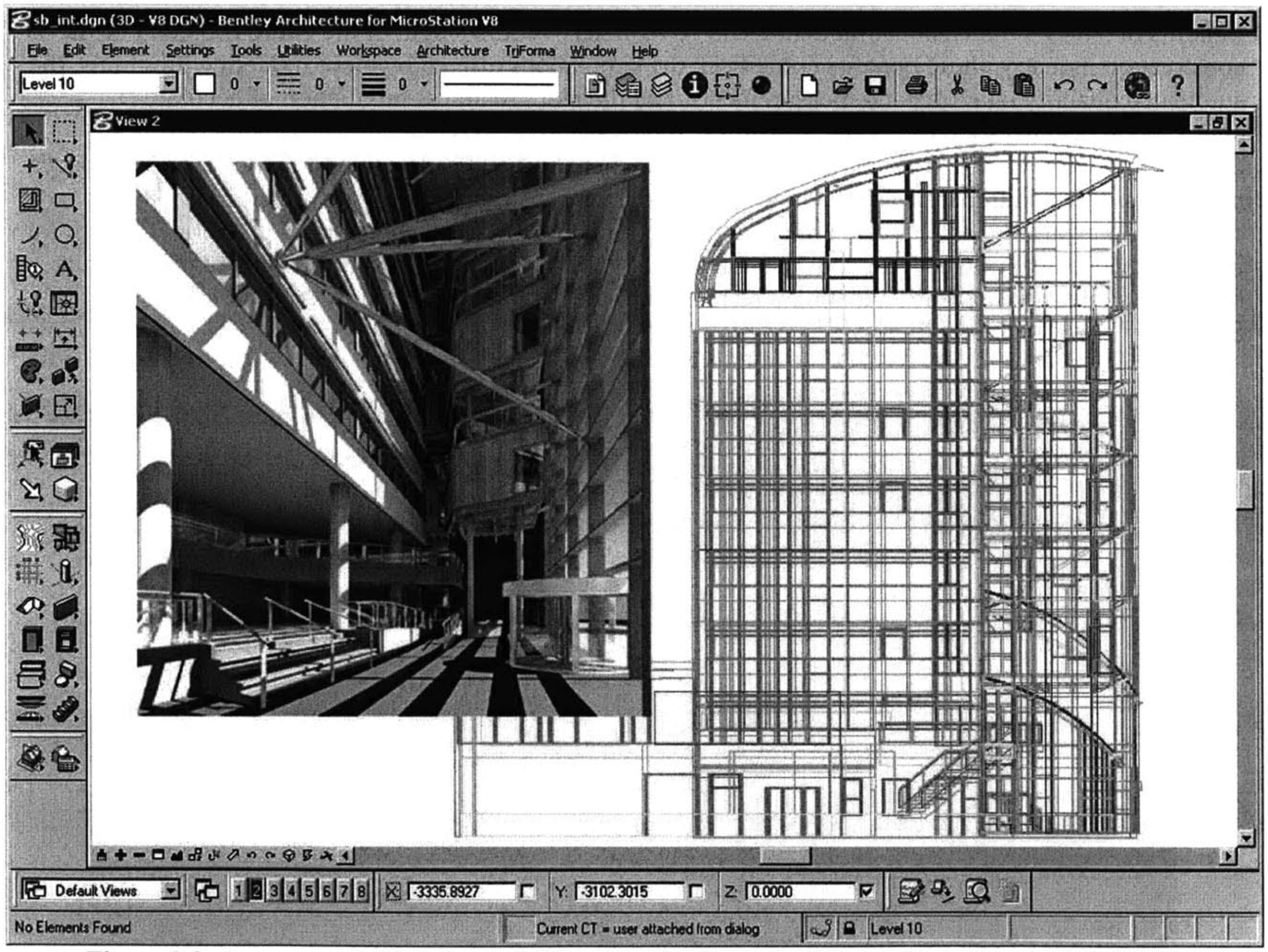


Figure 2.8: An example of Bentley Architecture's simultaneous 2 and 3-dimensional capabilities

Bentley Architecture is a BIM program developed on top of Microstation, the second most widely used drawing program in the engineering industry, and has been used on many large-scale projects throughout the world. In addition to high-quality rendering and animation as shown in the above figure, Bentley Architecture is capable of modeling, visualization, reporting, schedules, cost and program analysis, schedule simulation, and 4D design. Most important, however, is the program's ability to handle several standard file formats, including .DWG, .PDF, .CIS/2, and the IAI's IFCs. This offers program users the flexibility and workability they need for large, complex projects with multidisciplinary teams and a wide number of members.

Preferences between these two categories of BIM software programs vary depending on user needs. Although bidirectional editing creates a very effective operating environment because any changes to the model or to information are automatically reflected throughout all related project information, it also entails being able to handle the entire model any time project information needs to be accessed, which may require computer system upgrades to faster and more capable workstations because the project model could be a incredibly large file. Thus, some users may still prefer the multi-file approach to the single-file model because of its scalability even with the necessary additional management requirements and care in initial setup.

2.2.1 The Benefits of BIM

Benefits of 3 and 4-dimensional modeling can be realized over the length of the entire project. For the construction industry, these benefits come from the simulations offered by these modeling programs, the automated quantity take-offs and measurements, and the more seamless production of accurate construction documents. The contractor can use the model to analyze the constructability of highly detailed areas and visualize potential problem areas where limited headroom or cramped working spaces may necessitate additional measures or added care during construction. In less optimal cases, the contractor may also be able to catch mismatched coordination between engineering disciplines where for instance mechanical or electrical equipment and ductwork overlap with structural elements. The figure below illustrates a visualization that may be helpful to the contractor created by Autodesk Building System.

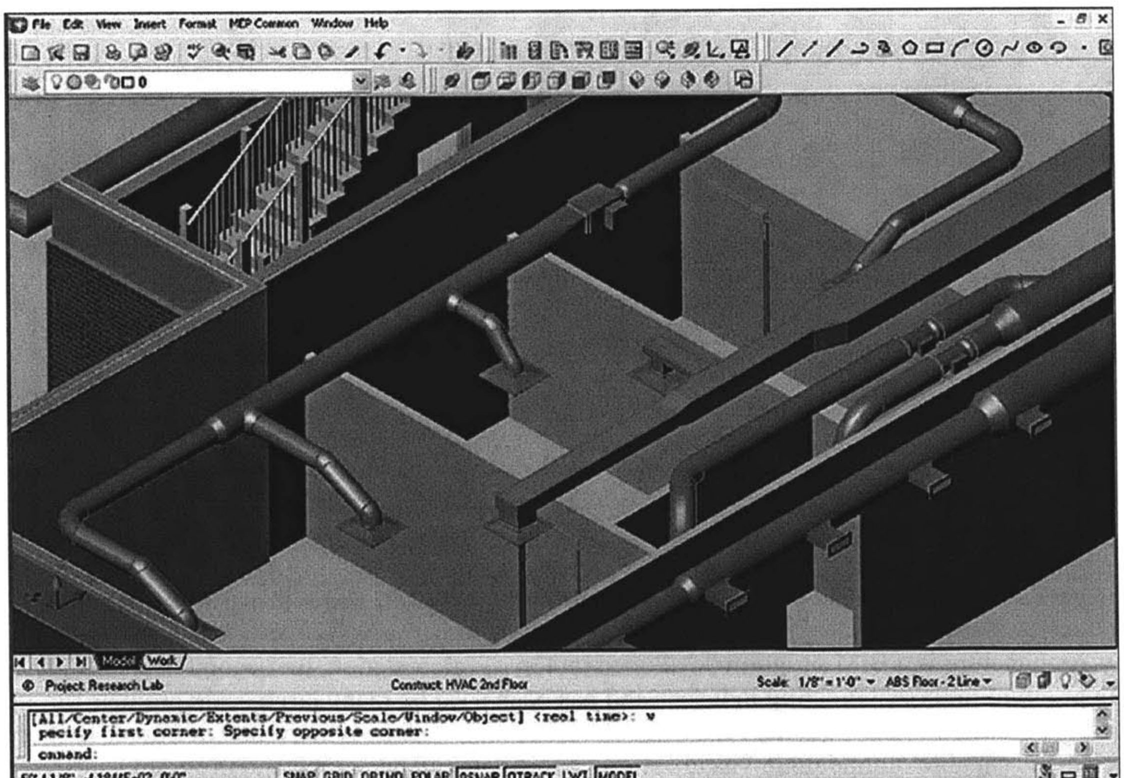


Figure 2.9: An Autodesk Building Systems view used for interference detection

This type of early-on constructability validation can save a considerable amount of time and money by preventing expensive rework or on-site corrections. Additionally, a central building model has the potential to heighten the level of involvement and communication between the contractor and the architect/engineer by simultaneously making design engineers more aware of constructability and field issues and encouraging construction team members to appreciate the design concepts and rationale behind certain engineering aspects. A 3-dimensional model can help each party visualize the concerns that the other may have and must eventually address, and with a better understanding of each other's needs, a much better end product can be realized.

Cost and time savings can also be achieved through automatically calculated quantity take-offs extracted directly from the model. The computerization of what would otherwise be manual quantity take-offs makes the cost estimations performed at any step of the project much more efficient and eliminates almost all sources of human error. These computer-generated take-offs can also be output in an acceptable electronic format to be immediately transferred into a cost estimating software program, saving even more time in the cost estimate portion of work for any given project. This type of task automation allows a free-up of manpower for other more valuable tasks that require personal engineering and construction expertise. In addition, these cost estimates that are linked to the project model can be used in value engineering analyses to examine details that could lead to cost savings or more efficient engineering design. Although value engineering may be seen as a benefit for the planning and engineering phase of a building project, the contractor can benefit greatly from a more efficient design, and constructability is almost always taken into account during value engineering assessments.

Accurate construction documents are much easier to obtain through a 3D model. A new method of monitoring construction and ensuring that things are being built to specification is to bring a handheld or PDA into the field that is capable of displaying the model and all related information. Especially with bidirectional systems where the entire model is contained within a single file, this can greatly enhance the on-site efficiency because rather than carrying large plans and documents on-site, everything can be monitored and back checked electronically through a small handheld device.

2.3 Construction sequencing and 4D modeling

4-dimensional project modeling has become more popular within the last few years, and Gehry Technologies has developed very sophisticated software on top of CATIA, the general product modeling program developed by Dassault Systèmes. Digital Project is considered one of the most advanced BIM programs available and offers support over the entire life cycle of building projects, including design and engineering, fabrication, construction project management, and on-site construction activities.

Digital Project has powerful 4D potential because it integrates Primavera scheduling software with 3-dimensional building modeling. The software allows users to view 3D models of construction information as components of the project contract documentation. Additional benefits are also available in the model package, including help with other project activities such as product coordination and control, building performance, cost estimating, 3D to 2D integration, digital fabrication, and onsite integration.

Below is a figure showing the construction sequence of the structural system for the Beijing National Stadium in China. The sequence was generated using Digital Project, a product of Gehry Technologies. The four pictures depict the major structural phases of the stadium construction.

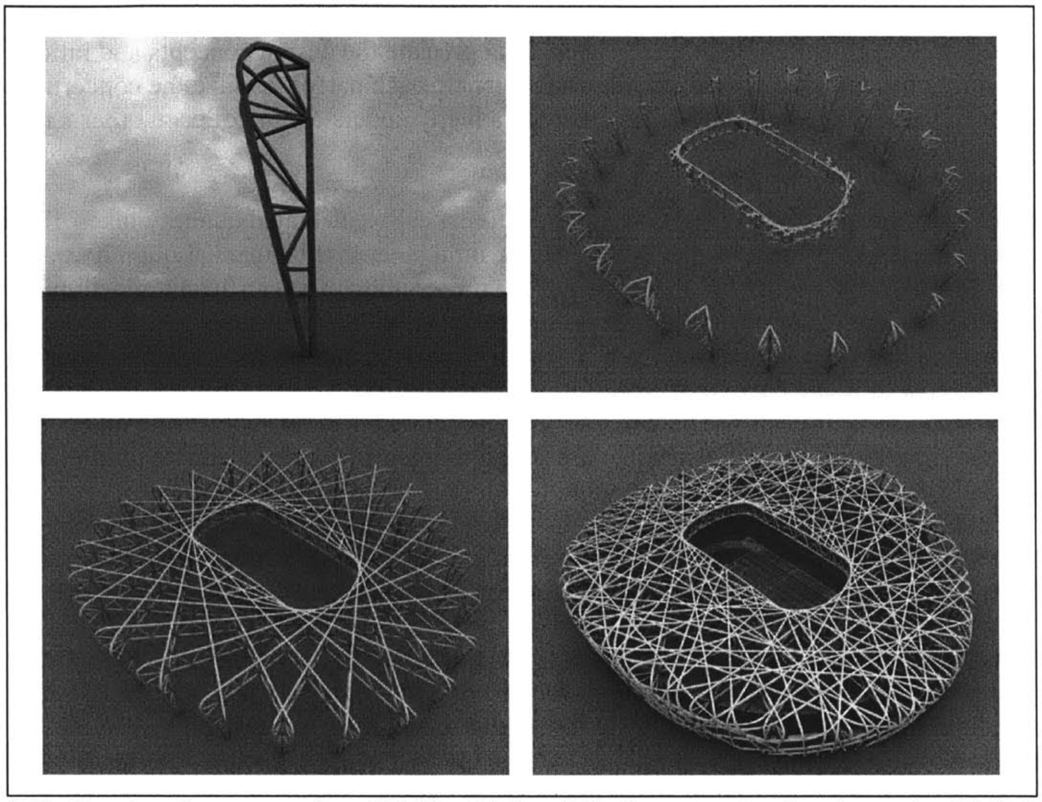


Figure 2.10: Construction sequencing of Beijing National Stadium structural system using Digital Project

2.3.1 The Benefits of Construction Sequencing

The ability to visualize the construction sequence in four dimensions is beneficial in two main regards:

- It assures efficient use of resources on site and helps the construction team find schedule inconsistencies and access or delivery issues
- It informs stakeholders and other project members of the construction approach and schedule in a manner that is coherent and easy to understand

Construction sequencing on various software applications including Building Project is being used to garner these benefits throughout the construction industry. In some cases, web cameras are being set up on site to track actual construction progress, allowing comparison to the planned 4-dimensional schedule.

2.4 3D Laser Scanning

An extremely vital component of a contractor's responsibilities is production of as-built drawings and verification of the actual construction against the original design. To produce as-built drawings and ensure that the construction is aligned with the design documentation, a robust construction monitoring program must be established. Photogrammetry is a standard technique utilized by contractors to obtain as-built geometries and to represent results in 3D computer modeling. The technique is carried out through a collection photographic images that are used to measure three-dimensional coordinates of points on an object or structure. This method is much faster than manual field measurement and input of data, but with new technological developments, the time required for collection of this as-built data can be reduced even further.

Through newly developed laser scanning technology and commercial software, modeling speeds can be increased up to four times that of photogrammetry. 3D laser scanning utilizes lasers that scan large areas for continuous recording of object configuration; this data is then stored on a computer in point cloud format which can later be used for 3-dimensional as-built data. Long-range 3D laser scanner systems can generate a 999 x 999 matrix of laser dots approximately 4 millimeters in diameter; with this amount of precision, the distribution of dots can be considered a continuous sampling of coordinates. These coordinates enable the measurements of components in terms of location, distance, linearity, and flatness, and the data is often used to ensure that no unexpected displacement or deformation has occurred to any beams, columns, or girders during construction. The figure below shows a laser scan system on the left and the subsequent 3-dimensional scan of a construction site produced by the equipment on the right.

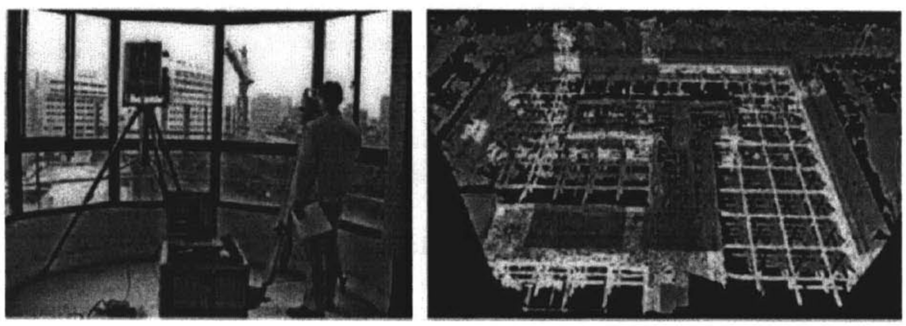


Figure 2.11: 3D laser scan system and the scan produced of a construction site

3D scanning can produce detailed models of the actual construction site with extremely small tolerances in error, and as mentioned above, these can be used for comparison with the original design model to ensure adequate accuracy. More scan imaging is shown below, with actual photographs of the construction site on the left and scan images on the right.

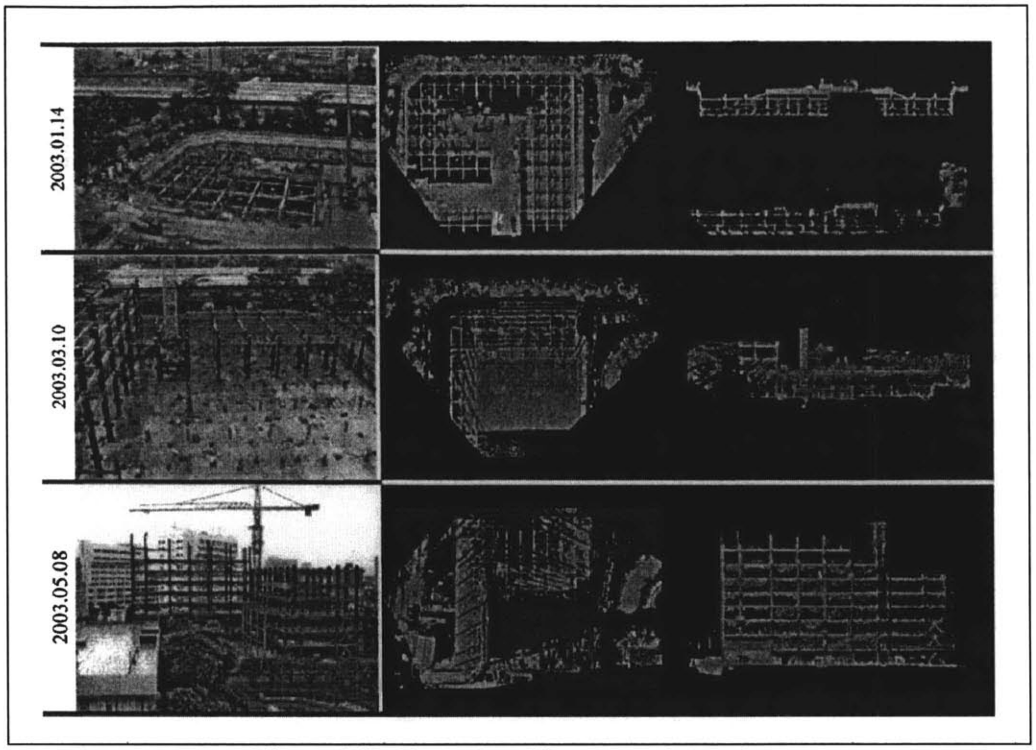


Figure 2.12: Examples of images and scan data

The scanning equipment must be coupled with a 3-dimensional scan information management system that serves as an interface to input, display, and inspect all information obtained from the equipment. This management system (SIMS) provides a computer environment for the following purposes:

1. Uploading scan records and files as well as construction records
2. Uploading data created through post-scan manipulation
3. Querying, browsing, and inspection of the available models and photographs
4. Comparison of the as-built models and construction documents or earlier as-built models

After the scanning equipment picks up the necessary data, these files are transferred into an appropriate format and saved on a central server running a database management system; when a user wants to access this information, he or she uses a web interface which communicates with the database management system through an ASP (active server page). The information is returned to the user via the same web interface. It is vital for this management system to have appropriate file transfer programs in order to manipulate the raw data from the scanner as well as to transfer files between different formats, such as .DXF, .DWG, .PTX, and .PTS. The figure below illustrates the basic system components of a SIMS.

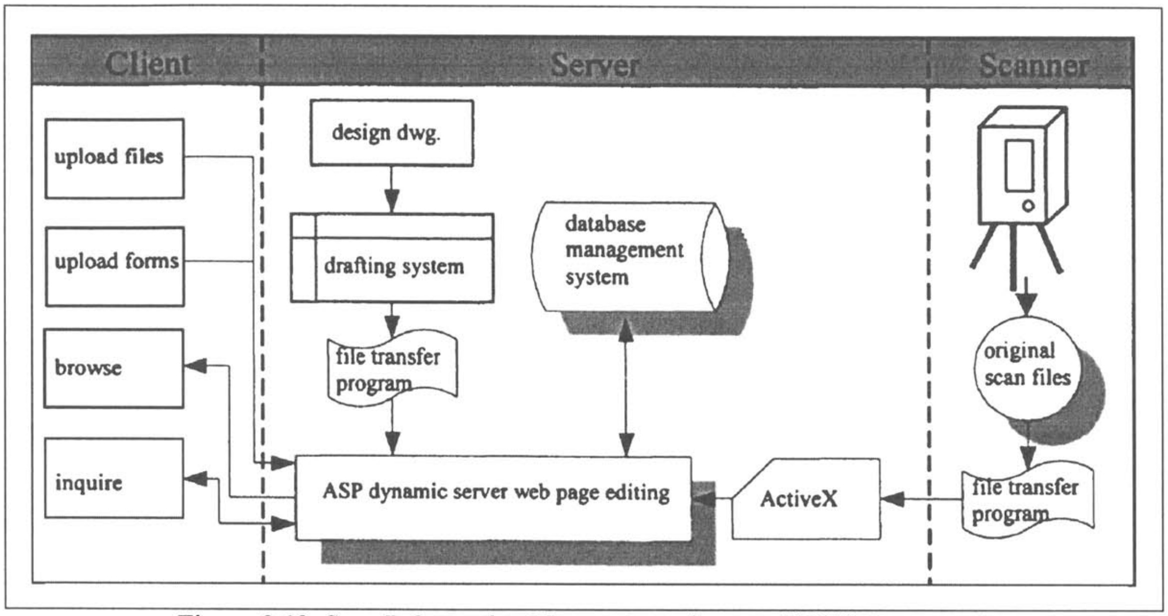


Figure 2.13: Scan Information Management System (SIMS) framework

2.4.1 The Benefits of 3D Laser Scanning

The benefits for the construction industry from this type of 3-dimensional scan information management system come in many forms. Dimension measurements, beam camber, or working tolerance inspections can be done with relative ease by utilizing the scanner and software system. Measurements can often be hard to take manually over large distances; scan information automates this process and eases the burden. This measurement capability can be extended to comparison with design documents for the purposes of dimension verification, often picking up errors or changes in the field that create inconsistencies with drawings and specifications. Scan data has also been used on projects as a record of machinery, worker, and material allocation: scans of the staging area are taken at intervals and kept as documentation.

Laser scanning can also be used to adequately measure quantities of soil and rock. An experiment on a transportation project for the Iowa Department of Transportation performed by Edward Jaselskis, Zhili Gao, and Russell Walters included a pilot project that attempted to measure the volume of stockpile on site as well as the volume of a nearby borrow pit. The on-site equipment, much like the equipment shown in Figure 2.11 above, consisted of a laser scanner on a tripod which was connected to a laptop computer (Figure 2.14).

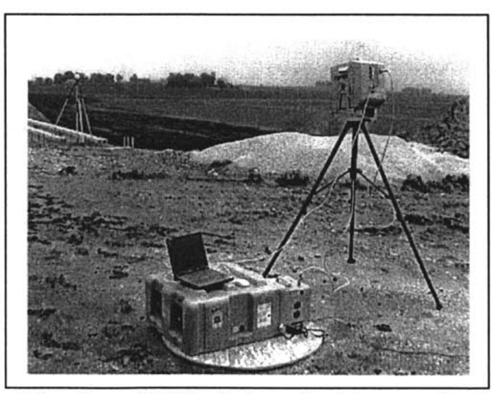


Figure 2.14: Equipment used for Iowa DOT pilot project to examine laser scanning performance

Two operators performed the necessary tasks, and their results were compared to those obtained by a parallel surveyor team utilizing traditional surveying methods. The overall technical results yielded from this study showed that the scanning accuracies were better than aerial photogrammetry for dimension measurements and that the stockpile volumes calculated were relatively close to the volumes obtained through traditional surveying methods (approximately a 1.2% difference). The figures below show the stockpile and the corresponding measurements and contours captured by the laser scanner.

Figure 2.15: Photograph of stockpile used in Iowa DOT pilot experiment

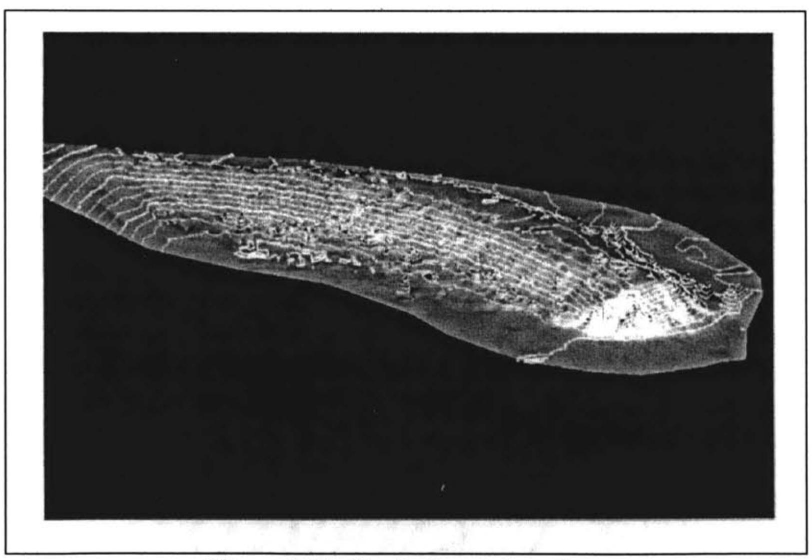
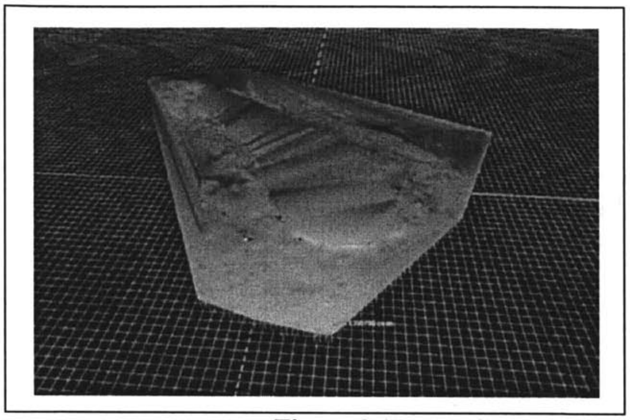


Figure 2.16: Stockpile contour lines



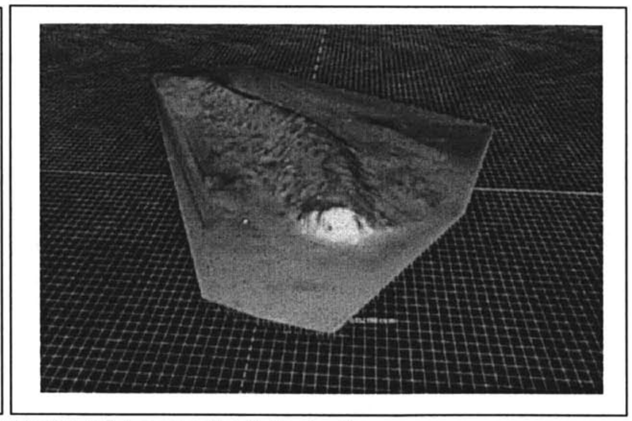


Figure 2.17 and Figure 2.18: Bottom and top mesh of stockpile

Additional results of the study completed by Jaselskis, Gao, and Walters concluded that laser scanning can be conducted by less personnel than required for surveying but that training and learning time negatively impacts the overall cost. In addition, the one physical drawback to the use of laser technology is the need for a direct line of sight to take measurements. Based on their pilot study, laser scanning costs approximately $3.43 per linear foot while traditional aerial photogrammetry methods yielded a linear foot cost of $2.66 (approximately 30% higher). The authors anticipated, however, that this per unit cost would be significantly reduced through further use and ultimately higher proficiency with laser scanning operations.

Overall, the results obtained from laser scanning do not necessarily require less time or effort than more traditional monitoring techniques but in most cases yield more accurate results. Currently, the use of 3D scan records as formal as-built construction documents has not been sanctioned or legitimized by the government and only serves purposes of internal use between the contractor, design team, and client. However, with its growing popularity, the government will soon need to examine the legitimacy of 3D scanning in the realm of as-built construction documentation. With more familiarity and research into the usage of laser scanning, the efficiency rates will increase and benefits will hopefully be easier to perceive.

3.0 OVERALL DISCUSSION OF BENEFITS PROVIDED BY INFORMATION TECHNOLOGY

The following section will briefly summarize the benefits arising from the specific IT developments mentioned in Section 2.0 of this report and will be followed by some discussion regarding the overall impact of information technology on the construction industry.

3.1 Summary of Methods Discussed

Electronic Document Management

More effective communication between the contractor and other project parties is the key benefit of EDM. Reduction of man-hour dedication to communication and coordination efforts can lead to considerable cost and time savings. A simulation by Back and Bell in 1995 concluded that when compared to situations where no electronic information technologies are utilized, the complete implementation of electronic data management can result in up to 85% time savings and 75% cost savings. However, it should be noted that within the construction sector, there are virtually no companies working without personal computers, the internet, and email; therefore, these time and cost savings estimates may have been applicable in 1995, but since then have certainly decreased substantially.

3D Modeling and Building Information Models

Pre-construction simulation offers many benefits to the construction sector because it provides a method of visualizing complicated, highly detailed areas that may be potential sources of difficulty. Additionally, it allows the contractor to assure that no design mistakes or constructability issues have been missed by the engineers and architects. Catching mistakes before construction or during the early stages of construction can save the owner from expensive rework or on-site corrections, and in design-build situations where the contractor and designer have partnered together, these situations should be avoided as much as possible. In general, these types of models can promote communication and coordination between the designer and the contractor, thereby providing more assurance that the design is constructed in a proper manner.

The automation of quantity take-offs and cost estimates through 3D models and BIMs can also lead to considerable cost and time savings and the free-up of manpower to perform other less tedious tasks that require more engineering analysis. These automated procedures can also be utilized in value engineering analyses for further construction cost savings and a more efficient design.

Finally, 3D modeling produces more accurate construction documents. These documents, especially if they are single-file 3D models, can be brought directly on site through PDAs or handhelds for field inspection.

A survey conducted by Griffis et al in 1995 showed that projects utilizing 3-dimensional modeling performed better in terms of cost, schedule, and rework: with a sample of 93 projects, the projects using 3D modeling garnered the following benefits:

- 5% reduction in cost growth
- 4% reduction in schedule slip
- 65% reduction in rework

A case study used to validate these survey responses revealed that for one particular project, an overall cost savings of 12% was realized through application of 3D modeling technology.

Construction Sequencing and 4D Modeling

Construction sequencing and 4-dimensional modeling assures efficient use of resources on site and can aid in identification of schedule inconsistencies or other logistical issues. Additionally, it can be used as a tool to help other team members or the client understand the details of the construction process as well as the intricacies of the overall project schedule. Studies conducted regarding the benefits of construction sequencing and 4-dimensional modeling, in particular the research performed by Koo and Fischer in 2000, argue that this technology, in addition to what has been mentioned above, is useful for anticipating safety hazard situations.

3D Laser Scanning

3D laser scanning benefits are most heavily realized in terms of monitoring techniques. As-built verification through dimension and volume measurements and tolerance checks is a large part of a contractor's responsibility. Higher accuracy and greater efficiency can be achieved for this task through the use of 3D scanning as opposed to more traditional monitoring and surveying methods such as photogrammetry. Although the per unit cost of 3D scanning is still higher than traditional methods, familiarity and further experience and exposure to this new technology will undoubtedly make 3D scanning the more attractive alternative from both a cost and quality perspective.

3.2 The Overall Impact of IT on the Construction Industry: Statistical Analysis

Very few studies have been conducted on the overall impact of information technology on firm performance. Mohammad El-Mashaleh, William O'Brien, and R. Edward Minchin Jr. have provided a statistical sample of IT utilization and relationships between this utilization and several pre-determined measures of firm performance (499-507). Data for this study came from 74 construction firms across the southeastern United States in the form of a web-based survey. The results of the authors' analysis showed a strong relationship between firm performance, individual cost and schedule performance and IT use; however, the authors could not find a correlation between profitability, customer satisfaction, or safety performance and IT use.

The variable of IT within each company use was represented as a number El-Mashaleh et al refer to as an "ITindex," a number calculated by asking each surveyed individual to assign a score to 48 different work functions that indicated what level of information technology was being utilized to perform each of these tasks. The levels ranged from 1 (where no or few electronic tools are used) to 3 (where the process is almost completely automated). The higher the calculated ITindex, the more information technology is used at the surveyed individual's firm.

In general, the analysis of El-Mashaleh et al provides empirical evidence that information technology impacts the performance of construction firms in a positive way. The following figure shows the relationship between schedule and cost performance (SC score) and the ITindex.

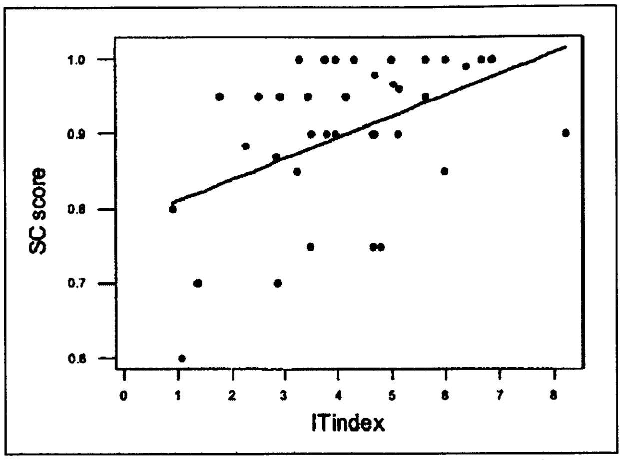


Figure 3.1: Regression plot for SC score (schedule and cost performance) and ITindex

According to the regression analysis, the ITindex had a 48.5% influence on the SC score. The authors also performed regression analysis on schedule, cost, customer satisfaction, and profit, weighting these factors jointly under an SCCP score. In this case, the analysis showed that the ITindex had a 35.5% influence on the score. The figure below shows the plot for the relationship between the ITindex and the SCCP score.

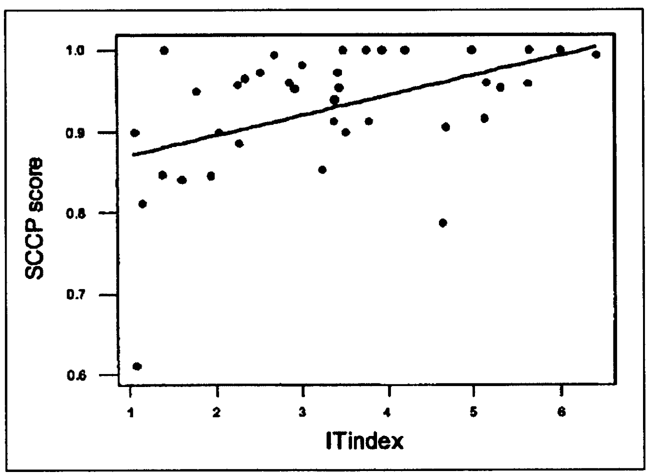


Figure 3.2: Regression plot for SCCP score (schedule, cost, customer satisfaction, and profit performance) and ITindex

The benefits of information technology use are clear from a time and cost savings perspective. As for the lost correlation between profit and IT usage, the authors believe that it may be due to the fact that investment in IT products and hardware is offsetting the savings provided by the added efficiency. This may well be the case as more companies have been budgeting more towards IT-related expenses as a result of the unmistakable correlation between IT usage and time and cost savings. These savings can only continue to grow as individuals and firms become more and more familiar with the newest information technology developments, and with this growing efficiency, the other factors which do not yet have a direct empirically proven correlation to IT usage (profit, customer satisfaction, and safety performance) may start to become more ostensibly affected.

4.0 HINDRANCES TO POTENTIAL BENEFITS

The relatively slow uptake of information technology in the construction sector can be explained by several key ideas, all of which stem from one overriding factor: the lack of information about IT inside the world of construction as well as the lack of informed individuals. By no means does this statement mean that individuals who work in this field are ignorant or slow-minded, but with respect to the subject of information technology, a far smaller percentage of people in the construction sector possess the technical breadth necessary to utilize information technology in a resourceful manner as compared to the architectural and design divisions of the engineering world.

4.1 Technical Obstacles

As mentioned in the previous section, the fact that the benefits of IT are highly immeasurable by firms who have very little exposure to such technology is a major obstacle for the widespread market penetration of IT. Without a reasonable amount of certainty that IT investment will be beneficial to a firm, that firm's management may be very unwilling to set aside an adequate budget amount for IT products and software. However, there is a substantial amount of literature available to the construction community explaining the benefits of information technology, how to make the most efficient use of simple and cheap IT tools, the best products for meeting a large list of specific needs, and what the latest IT trends happen to be. Countless empirical studies and surveys have been conducted in hopes of convincing readers that information technology has a positive impact on company productivity and efficiency. Those firms and managers who are more familiar with the latest trends in information technology understand that there are attainable benefits associated with the utilization of IT but that it will require initial investment and training to bring these benefits to fruition. On the other hand, those firms and managers who may be more traditional, risk-averse, or unfamiliar with IT developments will shy away from adopting new techniques and investing in technology they do not fully comprehend.

Even for those willing to invest in information technology, there are still other obstacles to overcome. Technically, there are some problems with the uptake of information technology in daily business because of trouble with the customization of software and web pages to suit company-specific needs. The construction sector is one of the few business markets where economies of scale do not necessarily come into play; thus, there are an exceedingly large number of construction firms throughout the world, each with its own particular methods, business practices, and general procedures. Because the IT needs of construction firms vary so greatly, off-the-shelf software packages often either need in-house customization, which many firms are not capable of with the IT staff at hand, or they must hire a consultant to customize the software for them. Both of these options can prove to be very costly, and with the exact monetary measure of potential benefits widely unpredictable in most cases, many firms forego the initial investment in software packages or other items. The level of coordination necessary to efficiently implement an IT solution can be very daunting, and it is a task that not every construction firm is willing to undergo.

4.2 Personnel Obstacles

Even the technical obstacles mentioned above can be partly explained by human resource problems. Uniformed management may dismiss pursuing IT solutions and improvements if they do not fully understand the potential benefits and best methods of implementation. An incompetent IT staff can hinder the company-specific customization of purchased IT software and in some cases can even cause software underperformance. Personnel issues are an incredibly important explanation behind the underutilization of information technology in the construction industry.

The level of investment in IT solutions is heavily influenced by management-level employees. If managers do not have enough knowledge to make informed decisions regarding information technology, an entire company's growth and efficiency can be affected. A company must have the vigorous support of its management-level staff if IT advancements are to be implemented; otherwise, the funding and necessary budget will never materialize.

Subcontractors, suppliers, and some fabricators often abide by very traditional operational procedures and methods. Underexposure to information technology solutions and general unfamiliarity with these processes causes individuals at these firms to be reluctant to adopt new methods of conducting daily work procedures. The level of exposure of individuals to information technology solutions affects companies as a whole. In addition, if construction firms do not have personnel dedicated to the upkeep of IT within the company, there is no source for the inflow of potentially helpful uptake of new technologies.

In summary, the following reasons are potential explanations for the slow uptake of information technology in the construction sector:

- Immeasurable benefits of utilizing IT developments
- Technology lag and difficulties with customization of software or web pages for company-specific needs
- Lack of managerial endorsement
- Unwillingness of subcontractors, suppliers, and even some fabricators to adopt new technologies and different methods of doing things
- Uniformed, insufficient, or nonexistent IT staff
- Uniformed staff members

Almost all these barriers to the successful and rapid implementation of information technology in the construction sector relate to the amount of information regarding the available alternatives residing within the community itself. The following section will discuss potential solutions to these widely encountered obstacles to IT usage growth.

5.0 STRATEGIES FOR IMPROVEMENT OF THE IMPLEMENTATION OF IT ADVANCEMENTS

By increasing the level of exposure to information technology advancements, the uptake of IT in the construction sector may be expedited. More informed and knowledgeable upper management should be the first step in increasing the implementation of IT advancements, and this can be accomplished by employing the following strategies:

- Employ the help of academia to inform the construction sector of the many benefits and the overall need for IT solutions in daily tasks
- Encourage software firms that produce IT solutions for the construction industry to expand marketing campaigns to include more information regarding the benefits of these solutions

The motivation for members in academia to help the inflow of information to the construction sector lies in possible opportunities to perform pilot studies and tests or to gain contacts for survey and questionnaire feedback in conjunction with various firms across the industry. For software developers, the obvious monetary benefits should be enough motivation to want to help increase information flow in the construction sector. With managerial support of IT solution implementation, changes to IT budgetary needs as well as employee training in the use of IT can finally be realized. The general education of employees falls under the responsibility of management-level individuals, and if these individuals can pass their knowledge on to all other employees through training and seminars on the topic of information technology, a larger percentage of workers in the construction industry will begin to fully understand the important role of IT and the beneficial impact it can have on productivity and efficiency as well as its ability to make a variety of daily tasks easier and less problematic.

The quantity of available literature on the topic of information technology is already quite astounding; the only hindrance is motivating people in the construction industry to read and understand it. The natural trend of the architecture and design engineering community towards more implementation of IT in a higher percentage of projects will eventually expose construction firms to a great deal of information technology. When the construction documents are transferred in more sophisticated forms rather than the traditional set of 2-dimensional drawings and a specifications, for instance in a 3-dimensional model package, or when the manner of data, file, and document exchange becomes more technologically sophisticated, the contractor will have no choice but to learn about these processes and advancements if he or she would like to remain competitive within the industry. However, it would be more beneficial for these companies to learn more about IT on their own and understand that there is an entire collection of benefits associated with proper implementation of these products. Heavier promotion of this available literature could be a great source of improvement in terms of the number of informed individuals within the construction sector.

The technological problems associated with the customization of IT software can be solved with a heavier level of effort put towards development of new programs or improvement of older versions of effective software. Highly and easily customizable software has the potential to attract a more premium price that can offset the higher development costs of IT firms. Firms that are looking for ease of use in IT business solutions may be willing to pay additional money for the added convenience. On the other hand, there are also construction firms that may just be looking for the cheapest and/or simplest solution, and these firms can be attracted through more competitive pricing.

The promotion of information technology in the construction industry has not been aggressive enough to produce premium results. For the most part, individuals still lack a great deal of exposure to the advancements and available solutions and have remained uninformed regarding the benefits of IT as well as the most optimal ways of implementation. The following list contains several suggestions for the improvement of knowledge transfer with respect to information technology:

- More informed and willing upper management and IT staff
- Academia helping the industry to become more informed about the need for IT and all new developments
- Software development firms becoming more involved with the promotion of information throughout the construction sector
- Software development firms making a greater effort to create (1) more highly customizable and easy-to-use software and (2) cheaper and simpler software
- Education through company-wide training, seminars, etc. (expanded employee training budget)

Implementation of these suggestions will lead to a much more productive and efficient construction sector over time.

6.0 CONCLUSION

The construction sector stands to gain much from recent IT developments, specifically from electronic document management, 3D modeling, construction sequencing, and laser scanning. There are many other technological advances and new software that, if implemented properly and effectively, have the potential to create substantial efficiency gains and cost savings through lower project costs, shortened schedules, and overall streamlining of coordination efforts between project teams.

Due to the general lack of circulation of important information within the construction sector, the successful implementation of IT advancements has been impeded. Because contractors feel they cannot fully measure the benefits that may be gained through the use of information technology in daily business, they do not want to risk the initial investment and time for training and learning. The lack of managerial endorsement, unwillingness of subcontractors, suppliers, and even some fabricators to adopt these new technologies, uniformed staff members, and ineffective or nonexistent IT staff can all be traced back to the general lack of exposure and information exchange within the entire industry.

This lag cannot continue for much longer. More and more problems will undoubtedly result from the growing technological rift between design teams and contractors if the construction industry continues to be unwilling to grasp new standards in software, construction documents, and general methods of doing business. Rather than reverting to competitive capitalist motivations, however, the construction industry should, with the help of other industries such as the world of academia and the IT software development community, try to inform its members as thoroughly as possible in the available IT solutions and the subsequent benefits these solutions offer. With less hindrance to the flow of information, it is strongly believed that more construction firms across the world will begin to invest more in information technology solutions and training for employees and subsequently start reaping desirable benefits.

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