CASE STUDIES ON THE USE OF INFORMATION TECHNOLOGY IN THE CANADIAN CONSTRUCTION INDUSTRY

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SUMMARY: *A series of eleven case studies were gathered from across Canada in the summer of 2002. These case studies define an initial compendium of Best Practice in the use of information technology (IT) in Canada. The professionals interviewed included architects, engineers, general contractors, and owners. Many of them are at the cutting edge in their use of IT. The documentation of their pioneering use of IT can demonstrate how useful these technologies can be and what potential pitfalls are of concern. The case studies cover architecture, engineering, construction management, and specialized contractors. The following technologies were demonstrated: 3D CAD; custom Web sites; commercial Web portals; and in-house software development. No case was found that used wireless communication or standardized data formats such as IFCs or CIMSteel. The following issues were identified: the electronic distribution of documents is more efficient and cheaper; the short time-line and the tight budgets make it difficult to introduce new technologies on projects; the industry is locked in one CAD system and it is difficult to introduce new ones; it is costly to maintain trained CAD and IT personnel; and companies that lag behind reduce the potential benefits of IT. Still, the industry could achieve substantial benefits from the adoption of IT if it would be more widespread.*

KEYWORDS: *Information technology; Technology use; Case studies; Architecture, engineering and construction industry; Canada.*

1. INTRODUCTION

Information plays two vital roles in all construction projects: it specifies the resulting product (design information) and it initiates and controls the activities required for constructing the facility (management information). Because information is such an essential component of construction activities, the evolution of information technology (IT) will undoubtedly have a profound impact on how organizations in the architecture-engineering-construction (AEC) industry operate. Indeed, the AEC industry is currently experiencing a paradigm shift from traditional paper-based to digitally based information exchange. Other industries such as airplane manufacturing and banking have adopted IT long ago and have benefited from it. The AEC industry is now poised to experience such a radical change. This paper documents a stage of this evolution in Canada.

It is difficult to assess the current use of IT in the industry as a whole because IT has been evolving very rapidly and because its use increases continuously. A series of case studies were investigated across Canada during the summer of 2002 to define an initial compendium of Best Practice in the use of IT. These case studies provide detailed and actual examples of how IT can be used successfully in construction projects. Several professionals involved in projects using IT were interviewed. They include architects, engineers, general contractors, and owners. Many of these professionals are champions that are at the cutting edge in their use of IT. The documentation of their pioneering use of IT can demonstrate how useful these technologies can be and what potential pitfalls are of concern.

This paper is organized as follows. First, the Canadian context is introduced with some statistics on the adoption of IT. Then, the case studies are presented. This is followed by a discussion about the technologies used, some technologies that are not used, general issues and a conclusion.

2. CANADIAN STATISTICS ON IT

The Canadian AEC industry is characterized by a level of fragmentation that is unparalleled in any other economic sector. Fragmentation gives rise to communication/coordination breakdown across project phases, disciplines, and subsystems. These problems influence facility performance, productivity and competitiveness throughout the industry. IT holds a lot of potential for the AEC industry because its purpose is to facilitate the exchange and management of information. The drastic reduction in computer prices and the increased power, usefulness and popularity of computers over the last few years have made IT more ubiquitous within the industry. Computers have become business staples. In addition, more and more computers are being connected together through the Internet, thus allowing firms located on different streets or in different cities, provinces, countries, or even continents to readily exchange information.

Statistics Canada has studied the adoption of the Internet among Canadian firms in the recent past and a few graphs are reproduced here to show this evolution. Figure 1 shows that its adoption has grown rapidly throughout all Canadian firms in the past four years (Charles et al. 2002; Stats. Can. 2003). At 76% in 2002, the Internet is clearly becoming standard in the private sector. The gain in the construction sector is more unstable since it has dropped by two points and fallen behind the average in the last year. For professional, scientific and technical services, which include architectural and engineering services, the adoption is much ahead with 92%. In comparison, the public sector is completely connected to the Internet since 99% of its institutions were using the Internet and e-mail already by 2000 (Peterson 2001).

Figure 2 shows the adoption of the Internet among construction firms and among professional, scientific and technical services, which include architectural and engineering firms. This figure clearly shows that "size of firm does matter when Internet adoption rates are concerned" (Charles et al. 2002). Almost all medium and large firms (20 employees and more) are connected to the Internet. A majority of small firms are connected to the Internet, and even more professional firms than construction firms, but still to a lesser extent than medium and large firms. Considering the fact that most firms in the AEC industry are small (95% of firms have fewer than 10 employees), it is likely that in large construction projects, some small firms are still not connected to the Internet.

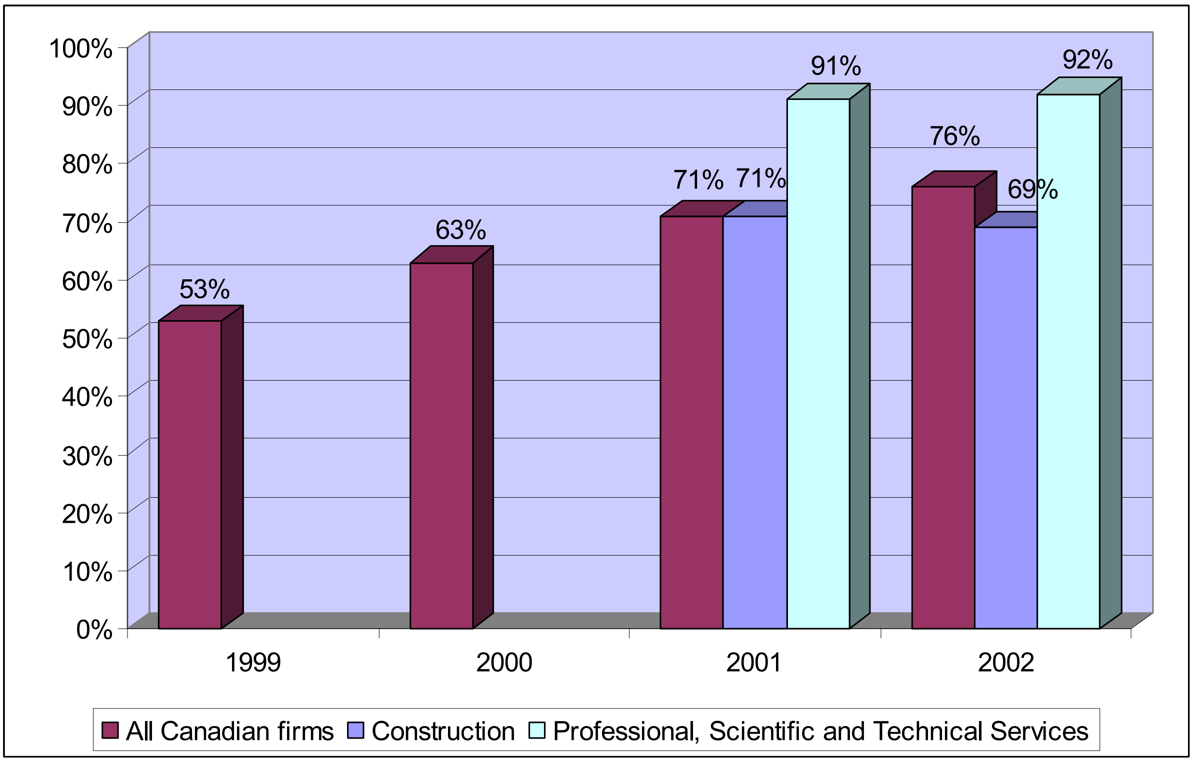

Fig. 1: Adoption of the Internet among all Canadian firms (Charles et al. 2002; Stats. Can. 2003).

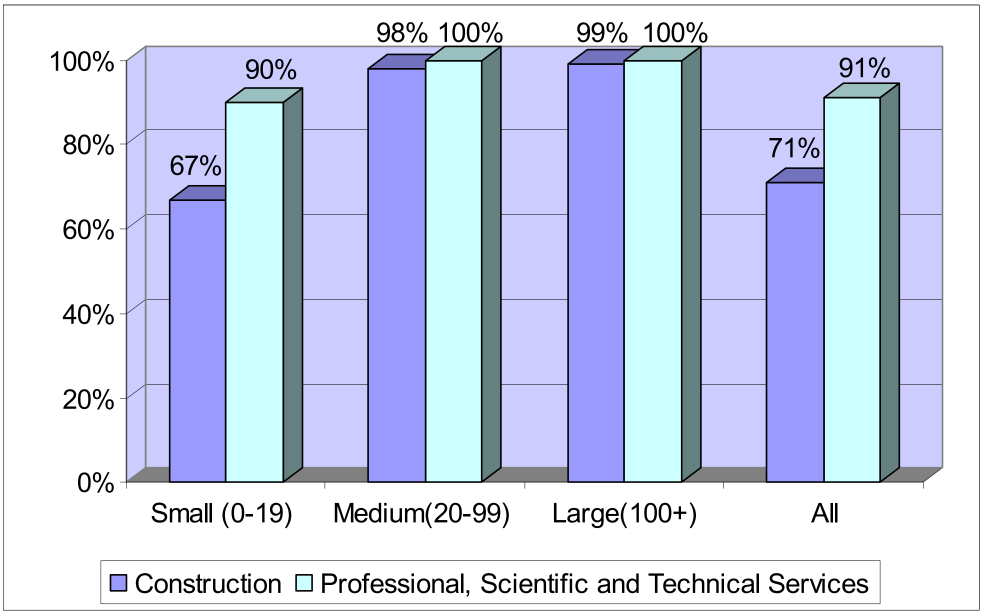

Fig. 2: Adoption of the Internet according to firm sizes in 2001 (Charles et al. 2002).

IT offerings can be seen as an "evolutionary chain of technologies" with organizations adopting, in sequence, more and more sophisticated technologies, starting with the use of computers, then the connection to the Internet, and then the creation of Web sites, which finally become interactive by supporting transactions (e.g., e-business applications) (Peterson 2001). Large firms are generally quicker in adopting "progressively more sophisticated technologies" (Charles et al. 2002). Thus, the next level of sophistication after being connected to the Internet is the creation of a Web site. Figure 3 shows that the number of firms in construction and in the professional, scientific and technical services, which include architecture and engineering, that have a Web site is 23% and 33% respectively (Charles et al. 2002; Stats. Can. 2003).

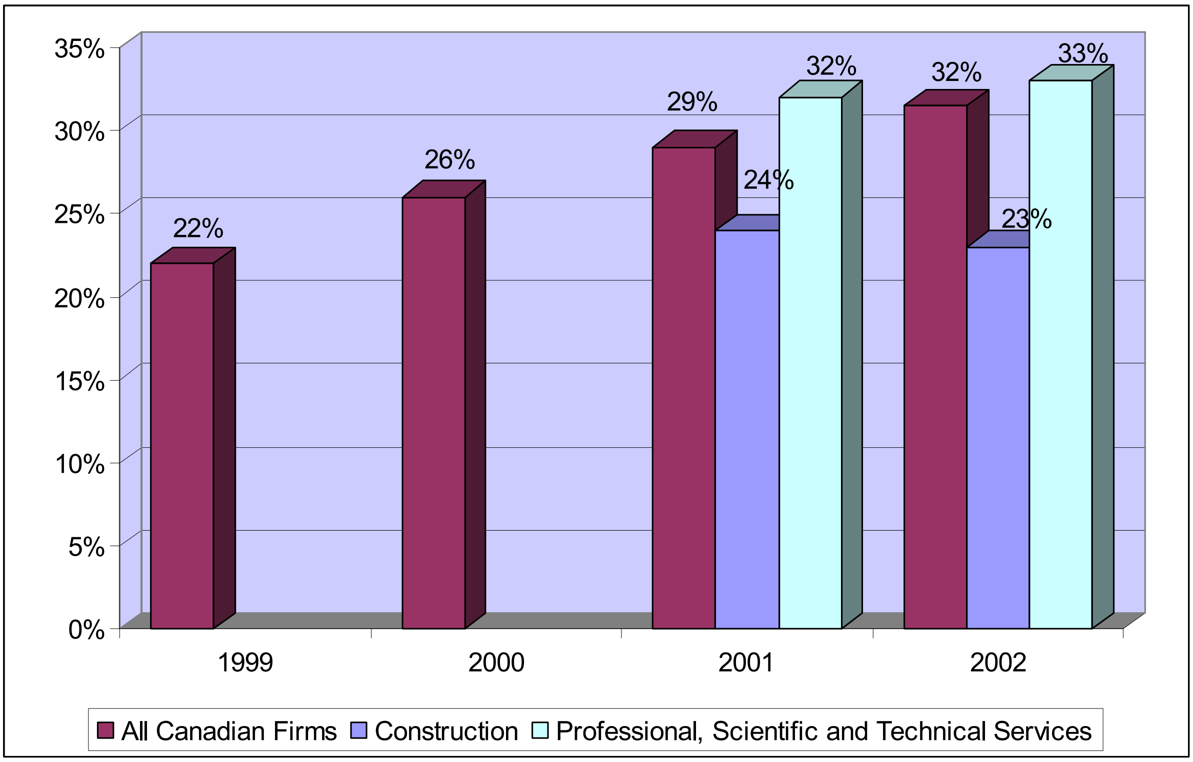

Fig. 3: Canadian firms with Web Sites (Charles et al. 2002; Stats. Can. 2003)

Figure 4 shows that the larger firms are also more likely to have Web sites. The highest level of sophistication in use of IT is to have Web sites that are interactive and that support transactions. A few examples are illustrated in the case studies and are discussed in a subsequent section.

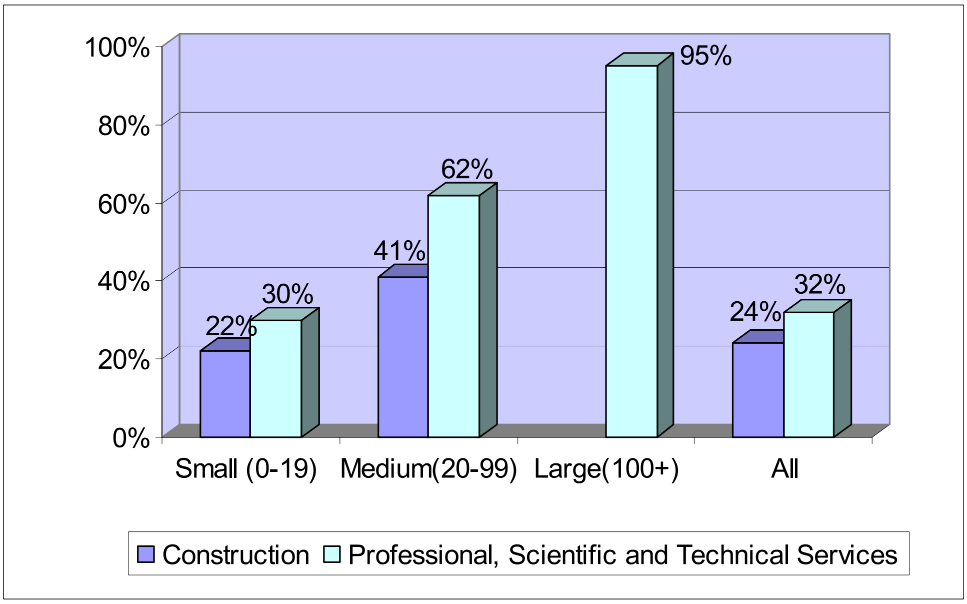

Fig. 4: Firms with Web sites according to firm sizes in 2001 (Charles et al. 2002).

3. CASE STUDIES

A set of eleven case studies were gathered from across Canada. Professionals who are at the cutting edge in the use of IT were interviewed and the findings were summarized in case studies. Each case study focuses on a construction project, is three to four pages long and is structured with the following sections: Project Overview, Project Information, Interviewee(s), Use of Information Technology, Benefits, Obstacles, and Conclusions. The case studies were numbered according to the location they were conducted: V for Vancouver, T for Toronto, M for Montreal, and F for Fredericton. A brief summary of each case study is provided below with its title and the names of the interviewees. Interested readers can access the actual documented case studies for additional information. The case studies can be viewed at the following Web site: http://www.ctn.etsmtl.ca/hrivard/ITCaseStudies/index.htm

The case studies cover architecture, engineering, construction management and specialized contractors. Table 1 indicates which case studies deal with each domain. A large dot: ● indicates that a domain is an important element of the case study; a smaller dot: • indicates that a domain is somewhat mentioned; and no dot means that the domain is not covered by the case study. The top header provides the identification number of each case study, which can be used to find the corresponding summary below. The following subsections provide a brief overview of each case study and the technologies used.

Table 1: Case studies versus domains.

Domain	**V1**	**V2**	**V3**	**T1**	**T2**	**T3**	**M1**	**M2**	**M3**	**F1**	**F2**
Architecture + Engineering	●	●		●	●		●		•	●	•
Construction Management	•		●		•		●		●	•	●
Specialized Contractors						●	•	●			

3.1 V1 – The Brentwood Mall Station of the New SkyTrain Millenium Line

Interviewee: Rod Maas, IT Coordinator, Busby + Architects Ltd., Vancouver, BC

The Brentwood Mall Station of the new rapid transit line in Vancouver was designed by Busby + Architects Limited. The 80-metre platform suspended over a highway is shaped into a ribcage and made of steel, laminated wood, and glass. In order to be able to model and design this complex structure, the firm had to adopt a 3D CAD tool. After some unsuccessful attempts with AutoCAD, they decided to turn to MicroStation because it offered a more comprehensive and simpler approach for rendering and creating a three-dimensional model. The station was modeled in MicroStation and then broken up into smaller sections to be exported to AutoCAD for preparing plans, sections, and details. The DXF format was used as the data standard that permitted this exchange of files. The 3D model allowed the architects to handle the complexity of the design, to find errors that otherwise would have been difficult to find on paper or in 2D CAD, and to prepare 3D views or walk-throughs for other project parties and the public. The design firm has been recognized with the Bentley/MicroStation 2000 award for its innovation in using a MicroStation platform for designing a transportation facility. Figure 5 shows two renderings of the station.

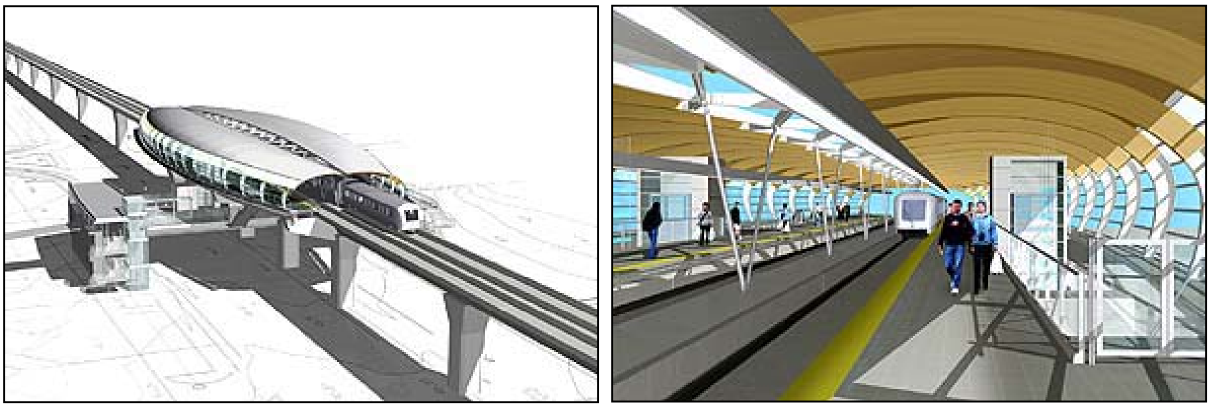

Fig. 5: Exterior and interior 3D rendering views of the Brentwood Mall Station. © Busby + Architects Ltd.

3.2 V2 – The Oltremare Project in Northern Italy

Interviewee: Rod Maas, IT Coordinator, Busby + Architects Ltd., Vancouver, BC

Busby + Architects Ltd. have also been responsible for designing a ten hectare marine theme park called Oltremare. This project, located in Northern Italy, is intended to be a tourist attraction as well as a facility for research, conservation and reproduction of endangered species dedicated to the Adriatic Sea. Designing a facility with participants located 10,000 km away can be a daunting task. Collaboration and communication were supported through e-mails and the setting up of a File Transfer Protocol (FTP) server. E-mails were used for the exchange of electronic documents or files of 'moderate' size. For larger files, such as CAD drawings, the FTP server was used. This server was made available through the design firm's web site and files were organized in previously agreed upon folders or directories. The FTP server could be accessed through a login. Busby + Architects Ltd. would upload project information at the end of every working day so that their Italian counterparts could access the server and download these same files the next morning. This tool proved successful in exchanging information with distant partners and they intend to use it again in similar projects. They are considering the installation of an Extranet within their Web site for achieving a better collaboration between project participants.

3.3 V3 – Construction is more than "Bricks and Mortar"

Interviewees: Project Manager, Company X, Vancouver, BC
IT Coordinator, Company X, Vancouver, BC

The third case study from Vancouver investigated the construction of a 100,000 sq. ft. six story building located in the heart of Downtown. The name of the project and the general contractor are not disclosed in response to a request of confidentiality by the company studied. So, for the purpose of this paper, the project is labeled Project Y and the general contractor is named Company X. A change of attitude has been experienced recently at this company with respect to computer-based innovations. One of the project managers says that "construction is more than bricks and mortar" when it comes to the management of construction operations. IT applications have become an important element of the success of this company in keeping control of their construction activities. Several software and Internet applications were used on Project Y. The company uses Gold Cost Accounting and Precision Estimating from Timberline. The first application is used for payroll and job costing while the second one is used for cost reporting, estimation and forecast. The company used Primavera Project Planner, or P3, by Primavera Systems Incorporated for creating a schedule and organizing the project activities. The company also used Prolog Manager 6, by Meridian Project Systems, to automate management functions and track projects from design to the end of construction. It is linked to Timberline to update it with the latest information coming from the site. It is also used to generate monthly reports on all aspects of the project. The Web Portal ProjectTalk was also used for procurement and collaboration over the Internet. It helped automate some project management functions such as purchasing, cost control, requests for information (RFIs), document management and field supervision. ProjectTalk helped also with keeping track of construction progress. For instance, at the end of the day, the site engineer might report on the system that the activity called "pouring concrete in slab" is now at 60% of completion. This percentage is automatically stored in a central database and can be transmitted to the Timberline cost system for budget control. With this system, the project manager can see from his office whether the project is under budget. Using this gamut of applications, Company X has been able to reduce costs, eliminate deficiencies, expedite the building process and coordinate more accurately procurement, delivery, and installation.

3.4 T1 – Centenary Health Centre Renovation

Interviewees: George T. Bitsakakis, Arch., Associate Principal, Dunlop Architects Inc., Toronto, ON
Dmitri Abramov, Web Database Developer, Dunlop Architects Inc., Toronto, ON

The first case study from Toronto presents an innovative in-house development called the Dunlop Database which was used to help in the design of a project worth more than a $1 million. In this project, a portion of the 10th floor of the Centenary Health Centre was renovated to accommodate the new Child and Adolescent Mental Health Unit, which was opened in July 2002. The Dunlop Database, a Microsoft Access-based application, was developed by Dunlop Architects Inc. to help capture, organize and use the firm's experience. The database organizes data about the firm's projects in terms of building types (e.g., hospitals, long term care facilities, and research labs) and room and space types (e.g., public rooms, staff rooms, exam centers, and washrooms). Standard templates have been defined for the different types of rooms and space to capture detailed information on all architectural aspects of the rooms (recommended dimensions, servicing and structural requirements, finishes, furniture, etc.). The templates reflect the evolution of best practices of the company over the years and also store knowledge about specific client requirements. The first step is to enter the basic project information and functional program requirements. The templates are then applied to the project's room list and the system automatically generates a project-specific "basic" database, which can be adjusted by the designers. The clients and consultants are also given access to the database through the World Wide Web to review status, provide comments or make changes. This unique system has helped the firm to increase its productivity, to learn from its mistakes, to benefit from its rich experience, and to provide better services to clients.

3.5 T2 – Hastings Manor

Interviewees: Miguel Ladouceur, Arch., Mekinda Snyder Partnerships, Toronto, ON
Pal Szabo, President, GSCNE Inc., Toronto, ON
Adel Kirollos, ArchiCAD Support, GSCNE Inc., Toronto, ON

The second case study from Toronto is concerned with the design of Hastings Manor, a five storey, 245 bed, long term care facility. This $30 million project is under construction and is scheduled to open in April 2004. Mekinda Snyder Partnerships, the architectural firm in charge of this project, used ArchiCAD in the design and documentation of the building. The advantage of this 3D object-oriented CAD system, according to the architects, is that it allows the creation of a Virtual Building that tracks all elements of the building, thus making it possible to manage a building throughout its life cycle. It works with spaces and objects instead of lines. It allows the designer to do "design rather than drafting," says Miguel Ladouceur. Building plans, sections and elevations, schedules (finishes, doors and windows), details, bills of materials, and virtual reality scenes are all derived from it. Figure 6 shows an example of a screen capture of ArchiCAD for the Hastings Manor. The project file can be shared among several users working on it concurrently. Other consultants' drawings were merged into the 3D model to check for interferences.

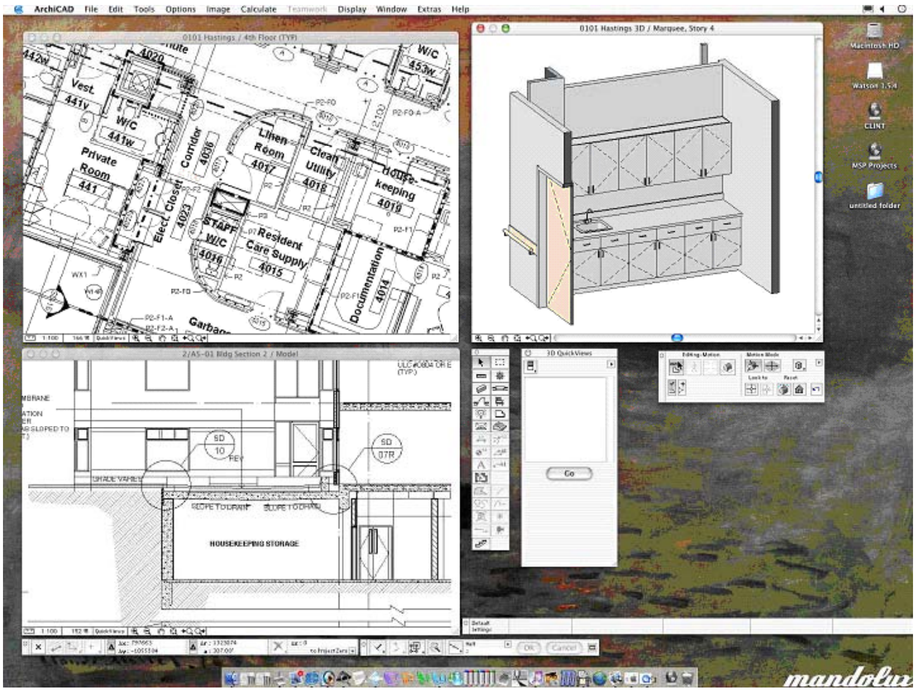

Fig. 6: ArchiCAD screen capture for portions of the Hastings Manor. © Mekinda Snyder Partnerships.

3.6 T3 – Hawthorne Village

Interviewees: Don Walker, Executive VP and CFO, Mattamy Homes, Toronto, ON
Wayne Matthews, Manager IT, Mattamy Homes, Toronto, ON

The third case study from Toronto investigates another example of an in-house software development, this time in the area of homebuilding. Mattamy Homes, Ontario's largest homebuilder, recently completed the first four phases of a community called the Hawthorne Village containing about 1500 lots. This firm has experienced a large growth in the past five years and has been able to handle such large projects because of the Mattamy Database. The in-house development of this system started by the acquisition of an accounting and contracting application upon which was built an application for planning and tracking the production. These applications formed the foundation of the system that was augmented with a production scheduling application (which helps in scheduling site work, manpower, trades, material ordering, and project staff requirements); a décor and sales application (which ties the sales offices with the head office); and a customer service application (which helps keeping track of all customer information). "Current and up-to-date production scheduling information was always available to our trades through our Supplier Website. This allowed each of our suppliers to know well in advance our requirements and their commitments. During the course of construction, the progress of each house was constantly maintained", explains Matthews. This project experienced extremely brisk sales and its magnitude could only be managed through the shared real time access to this comprehensive and integrated information system. Mattamy has earned many prestigious distinctions for Hawthorne Village such as the Project of the Year 2002 awarded by the Ontario Home Builders' Association and the Community of the Year 2002 awarded by the Greater Toronto Home Builders' Association.

3.7 M1 – How the Eaton Building Became "Le Complexe les Ailes"

Interviewees: Jean-Luc Dion, Eng., Director of Design and Construction, Ivanhoé Cambridge, Montreal, QC
Louis Lemay, Arch., Owner, Architects Lemay et Associés, Montreal, QC
Normand Leboeuf, Structural Engineer, Pasquin, St-Jean et Associés, Montreal, QC
Rocky Roy, Eng., Construction Manager, Pomerleau, Montreal, QC

The prestigious Eaton Building housed a department store for almost 75 years in downtown Montreal. This ten-floor patrimonial building, bought by Ivanhoé Cambridge, was completely renovated to a cost of $248 million and opened to the public in August 2002. The five lower levels of the renovated building contain a commercial gallery with one main tenant and many smaller stores while the upper four levels contain office spaces. A grand atrium was built in the center to let daylight penetrate the building all the way down to the subway level. The renovation also provided improved energy efficiency, acoustic treatment and cutting edge telecommunications infrastructure. Lemay & Associates, the architects responsible for the project, have moved their design methods over the years toward fully digital designs using different commercial applications. "Now we do the digital model first, while before we used to build the 3D model after the building was designed," says Louis Lemay. They first defined empty volumes, then worked on the "skin" of the building and the spatial concept of the interior – all using a 3D model. This 3D model was also used as a means of communication right from the beginning. Another technology used in the project is the commercial Web portal Bricsnet which enhanced project collaboration by providing a central repository for all project-related information (this is similar to the portal used in case study V3). It was the first time such a technology was used by all involved parties and so only a subset of its features were used. It served as a central repository for design information, correspondence (e.g., requests for information, minutes of meetings, performance reports, and communications with the owner), and digital pictures documenting the progress. However, the construction management aspect was not handled by Bricsnet since Pomerleau, the general contractor, had developed its own construction management system. This system tracks the progress of the project, handles contract administration, and manages directives and change orders. It also interacts with Microsoft Project by for scheduling and with Precision Estimating by Timberline for cost estimation and control.

Fig. 7: Night rendering of "Le Complexe les Ailes". © Architects Lemay et Associés.

3.8 M2 – A Global Solution for a Global Corporation

Interviewee: Jean Thibodeau, VP. Information Systems, Groupe Canam Manac Inc., Boucherville, QC

Canam Steel Corporation is a subsidiary of Canam Manac that encompasses steel work detailing offices in Canada, USA, Romania and India as well as sixteen steel production plants throughout North America. Canam Steel has developed a collaborative infrastructure that is tailored towards the specific needs of the company and team members in structural steel projects for buildings and bridges. They integrated in-house developed technology with commercial software. The collaborative infrastructure consists, at the first level, of an electronic document management system based on Lotus Notes and Domino.Doc that captures, stores, accesses, and keeps track of all project documents, including project correspondence and engineering drawings. Another level of support provides basic collaboration capabilities including real time collaboration and workflow management. Estimating is done using in-house estimating programs that identify all the components and that consider the capacity and performance of the various plants. When the company is awarded the contract, the contract documentation is generated automatically. Currently, once the approved construction documents are obtained (sometimes electronically), the takeoff is carried out manually because standard 3D product models are not used. An Advanced Bill of Materials system optimizes the use of materials based on stock availability or purchasing opportunities. Then, detailing is done and each component is assigned an ID mark to track it throughout the process until it is delivered on the construction site. "For a project like the Boston Convention Center (BCC), we are talking about 33,000 pieces of steel… we have full tracking of all these pieces," says Thibodeau. He adds, "About one hundred to one hundred and twenty five detailers worked for the BCC project, and those detailers were located in Quebec, USA and Romania. All the transfer of information between those sites was done electronically."

3.9 M3 – E-Commerce Place Phase I

Interviewees: Michel Lee, Eng., Project Director, E-Commerce Place, Montreal, QC
Olivier Legault, Associate Architect, Béïque, Thuot, Legault Architectes, Montreal, QC
Louis Gagnon, Eng., Construction Manager, General Contractor, AXOR, Montreal, QC

The E-Commerce Place is a building complex in Downtown Montreal consisting of three buildings with over 130,000 m2 of floor space that integrate several existing heritage buildings. The first phase consists of a twenty-seven story high-tech building that incorporates innovative infrastructure aimed at providing maximum flexibility for the future tenants. A 3D model was used to do numerous urban and volumetric studies to ensure the most positive impact on the neighbourhood. This 3D building model in conjunction with a 3D digital representation of the downtown core that Legault has been developing over the last ten years, allowed the proper integration of the building complex into the city in addition to enabling precise sun-path and sun-shade studies to evaluate the impact of the building complex on neighbouring facilities. As for the construction management of the building, most documents and communication were exchanged electronically and reflect in a way the name of the project. Drawings, requests for information (RFIs), directives and change orders were all sent and received electronically. Even procurement and bidding were managed electronically through e-mail. AXOR, the general contractor for the project, has been implementing a private document control system based on Lotus Domino.Doc. This system stores all documents and communications related to a project in a document repository that facilitates keeping track of those documents throughout the duration of a project. The system is not meant to be accessed by other project participants, it is meant to store in a structured way all kinds of documents and communications to clients, consultants, suppliers and subcontractors. This system is fully integrated with AXOR cost and time control systems. AXOR uses, among other applications, Primavera and Timberline for planning and estimation. The budget and cost control are handled by a system developed in-house. The system at AXOR helped in the coordination of the constant flow of information among the different participants, which is essential in fast-track construction as was the case for this project.

3.10 F1 – The Centreville School Renovation and Addition

Interviewee: Ed Goguen, Principal Architect, Goguen and Company Ltd., Fredericton, NB

An addition of $600 000 and a renovation of $2.14 million for the Centreville School, New Brunswick, is scheduled for completion in the fall of 2003. This project, designed and managed by Goguen and Company Ltd., makes significant use of IT. A digital camera was used to take pictures of challenging renovation problems. These pictures were linked to CAD plans and included in the bidding documents. These were very much appreciated by the contractors, resulted in fewer questions, and saved time during design and tendering. The firm makes extensive use of the object-oriented CAD software Autodesk Architectural Desktop and they generated 3D renderings for the client. The Web portal CINet was used as an electronic plans room to broadcast the project information to potential bidders. A Web site has been developed by the firm to support project collaboration. Each project hosted on this site contains the following topics: contact information for the participants involved, plans, specifications, and digital pictures documenting progress. The firm has also developed an electronic filing system to ensure that all project related files are organized in a consistent manner by the personnel.

Fig. 8: The Centreville School (left) and a rendering of its addition (right). © Goguen and Company Ltd.

3.11 F2 – Refurbishment of Colson Cove Generation Station for NB Power

Interviewee: Bruce Lundrigan, P.Eng., Project Controls, N.B. Power, Frederiction, NB

A $750 million project will upgrade the generating station of Colson Cove to satisfy current environmental emissions standards and to be capable of using more fuel options than only heavy fuel oil to generate power. The mechanical contractor on the project used Plant Design System from Intergraph to generate a 3D model of the plant, which was used to check for interferences in design and in construction planning. The project was in the pre-construction phase at the time of the interview, was started in Fall 2002 and will end two years later. The owner, NB Power, was planning an information management system to handle communication among all participants in the project. Primavera Project Planner was selected for managing activities, schedules, and resources. The contractors will be responsible to update the level of progress by e-mail. Primavera Expedition is being considered for contract management and communication between project participants. Version 8.5 of Expedition allows project information to be accessed via the Internet and a Web browser.

4. TECHNOLOGIES USED AND RELATED ISSUES

The vast majority of documents used on the case study projects were created electronically. Although we have come to expect this of today's projects, this is a stark contrast to the recent past. Today, we talk more about how documents are exchanged than how they are created.

Several kinds of information technologies were found to be used in the projects studied: 3D CAD was used during the design of several projects; custom web sites were developed to facilitate the exchange of information; a few commercial Web portals were used; and a few companies carried out extensive in-house software development to automate some of their processes. Table 2 lists the case studies in which a given technology was used. Issues about 3D CAD, custom Web sites, Web portals, and in-house development are discussed next.

Table 2: Case studies versus technology used.

Technology Used	V1	V2	V3	T1	T2	T3	M1	M2	M3	F1	F2
3D CAD	✓				✓		✓		✓	✓	✓
Custom Web Site		✓		✓		✓				✓	
Commercial Web Portal			✓				✓			✓	✓
In-House Development				✓		✓	✓	✓	✓		

4.1 3D CAD

In the last 20 years, Computer-Aided Drafting (CAD) has evolved from the computerization of the drafting board dealing with geometrical entities only (e.g., lines, points, and arcs) to customizable design environments. Recently, this technology has evolved toward 3D and product modeling (e.g., ArchiCAD and MS Visio).

The advantage of 3D CAD as stated by Lemay is that "now the client will know what he will get and engineers will know what is the goal right from the start" [M1]. The 3D model helps engineers to better visualize and discuss the implications of the architecture on the engineering systems. The architect, the owner, and everybody interested in the project are able to visualize the building a long time before it is built. "If [people] see the model and you can actually sit them in front of a computer and look at any view they want [of the model] they can understand it a lot better," says Maas [V1]. 3D CAD allows the design of more complex structures and helps identify and resolve errors that are not easily observed from traditional paper-based or two-dimensional CAD (e.g. the train station) [V1]. Furthermore, a 3D model allows the integration of a building into the city space through volumetric studies and precise sun-path and sun-shade studies as was done for the E-Commerce building [M3].

However, the 3D model is still not usually shared among all project participants, as was the case of "le Complexe les Ailes", where they relied on the traditional information exchange with DWG files. With such an approach, it is difficult to maintain consistency of information among the different design participants. Leboeuf, the structural engineer, believes that the sharing of a 3D model is necessary only for special projects with complex geometry [M1]. Some of the recently established data exchange standards may facilitate data transfer between computer applications in the future as discussed in a later section.

4.2 Custom Web Sites

The level in the "evolutionary chain of technologies", presented in Section 2, that comes after the use of static Web sites is the level of interactive Web sites that support transactions. There are two ways to reach this level: one way is the in-house development of a custom Web site; the other way is the adoption of a commercially developed Web portal, which is discussed in the next sub-section. Several projects investigated used custom Web sites with varying levels of capabilities. For example, Goguen and Co. has been developing its own custom Web site, which provides contact information and a repository of the latest design documents for a given project [F1]. In another case, Busby + Arch. Ltd is considering replacing its FTP server with a Web site that would act as a repository [V2]. In the case of Dunlop Architects, the custom Web site gives access to owners and collaborators to the proprietary database they have developed [T1]. Similarly, Mattamy has a Web site linked to its system that gives detailed scheduling information to their suppliers [T3]. A key factor to consider when choosing this approach is that, depending on their complexity, custom Web sites demand considerable resources in development, training, operation, and maintenance. However, custom Web sites adjust better to the particular needs of the company.

4.3 Web Portals

Web portals have been developed to capture the phenomenal opportunities for communication and collaboration provided by the Internet specifically for the AEC and facility management industry. A portal is a web site that offers a broad array of resources and services to attract and keep a large audience and aims to become its main entrance to the Internet (e.g., Yahoo or CNN). There is currently fierce competition among a few recent e-businesses in the U.S. to establish portals for the AEC industry providing functionality such as project-hosting, on-line meetings, searching trade directories, bidding, procurement, search engines, fora, and much more. Web portals allow collaboration and information exchanges in a fast and efficient manner regardless of the distance. Commercial Web portals were used in four of the case studies.

For “Le Complexe les Ailes”, the commercial Web site was mostly used to coordinate thousands of drawings for the project. According to Dion, the greatest beneficiary was the architect since it was easy to update and coordinate drawings. In the words of the architect: “everything is readily available; you don’t have to ask for the latest drawings, just go to the portal and get them”. All users received automatic notification of changes made by the architect. Hence, the whole team always works with updated building plans. But, according to Lemay, “these technologies are useful mainly for big projects; small projects are not worth the investment”, and in any case, regular face-to-face meetings are still considered necessary [M1].

In the [M1] case, the portal was not as extensively used as planned. It was mostly used during pre-construction, but obstacles appeared as the project team realized that most subcontractors did not have the technology for tendering on-line. “If on-line tendering is imposed, there would be a great risk that many qualified subcontractors won’t be able to participate and the process becomes less competitive,” says Lemay. Downstream construction management tasks were also limited due to the lack of technology adoption of the subcontractors. According to both the architect and the project manager, Web portals should play a more active role during construction to take advantage of the construction management capabilities of commercial Web portals. Dion points out “there is a resistance to change that comes from people whose jobs rely primarily on skilled construction work; information sharing is not on their priority list. In the future, a portal should be able to synchronize the master schedule with sub-schedules, especially for complex projects that involve many contractual packages,” says Dion.

In the [V3] case, the Web portal was also found to be advantageous because it provided access to all the project information 24 hours a day, seven days a week. However, the Web portal did not provide the results expected because the project team was using it for the first time. Company X is optimistic that they will soon get the new tools fully deployed and used. The advantage of having a central location for drawings, schedules, project documents, and photos will help them to keep accurate control of the project.

4.4 In-House Development

Developing an in-house system is a demanding endeavor. In the case of the Dunlop Database, they realize that their “expertise was limited to building design, not software design, and [they] decided to bring on a specialized consultant who had worked on other complex databases,” says Bitsakakis. Also, they realized that they would “need someone on staff full time who could design the front end, tailor it as required over time and manage it on a day-to-day basis,” says Bitsakakis [T1].

Matthews describes the development of the Mattamy Database as follows: “Our focus was on the integration of systems, and not on purchasing new applications. … What we really wanted was to develop a single application to manage all the project data, starting from the very first activities to the very last, and that’s exactly what we did. Now we have all our data about scheduling, customer service, budgeting, estimating, accounting, contracting, sales and warranty issues in one place.” Developing the sophisticated Mattamy database in-house was a big challenge. Mattamy has retained an IT staff of five professionals for continuous improvement of the system. Although initial investments on the development and maintenance of this database were significant, the firm is confident that its long term benefits, in terms of increased quality and saved time, will be more rewarding [T3].

In-house software development may be more expensive, but it could give an edge that is then unique in the industry.

5. MISSING TECHNOLOGIES IN THE CASE STUDIES

There are a few significant and promising technologies that were not found in the case studies. These are data standards and wireless technologies.

There are many computer applications used throughout the life-cycle of a construction project and very few applications can share data. Too often participants need to read the output generated from a computer application and enter this data manually into another application. Much technological development has gone toward the ability to transfer data among the various participants and their respective computer applications. This can be done with two methods: either by providing direct translators, or by defining a standardized data format. With the first method, a translating program is required for each pair of applications that need to communicate. The role of this translating program is to convert output data from one application into input data for another one. An example of this method is the integration provided by Timberline Inc. between its cost estimating application, called Precision Estimating, and scheduling applications, such as Primavera Project Planner or Microsoft Project, that is achieved through a direct translator called the Scheduling Integrator. These applications were found in case studies: [V3, M3, and F2]. This method becomes impractical with more than a handful of applications because the number of translators required explodes and the maintenance of this scheme is expensive in the long term (e.g., all translators for a given application may need to be updated when a new version is released). It is the same situation with proprietary file format such as DXF, which was used to transfer geometrical information between MicroStation and AutoCAD in [V1].

With the standardized method, every application generates output data files and reads from input data files according to a standard format. Such neutral files can be passed along to any applications. The main advantage is that the applications in the integrated system are not affected by the addition or removal of an application. Two standardized data formats have been proposed recently that hold much promise. The International Alliance for Interoperability (IAI) has developed a standard called the Industry Foundation Classes (IFC). This standard provides specifications for a set of standardized object definitions, which allows the transfer of information between software applications throughout the AEC building lifecycle (Froese et al. 1999). Many commercially available applications already support version 2.0 of this standard (IAI 2002).

The first extensive and documented use of the IFCs in an actual building project was for the design and construction of the Helsinki University of Technology Auditorium Hall 600 in Finland (Fischer and Kam 2002). This USD $5-million capital project started in October 2000 and was completed in February, 2002. The IFCs allowed a seamless data exchange between many computer applications (i.e., architectural applications, mechanical design applications, life-cycle cost analysis, visualization, cost estimating, and scheduling). This capability and the application tools used expedited design, allowed the consideration of more design alternatives, and improved the quality of interdisciplinary collaboration. The potential of this technology was clearly demonstrated.

Another standard focusing on structural steel construction is called CIMsteel Integration Standards (CIS). CIMsteel stands for Computer-Integrated Manufacturing for Constructional Steelwork (CIS 2002). The American Institute of Steel Construction (AISC) endorsed this European-developed standard for the electronic exchange of structural steel project information for the North American structural steel design and construction industry in 1998. CIS/2 allows engineering software to export data from one application to another as well as more advanced data management capabilities to enable data sharing and concurrent engineering within a database management system. CIS/2 has already been adopted by several software vendors in several countries. CIS/2 is compatible with the IFCs.

Although information exchange standards hold tremendous potential for the industry, none of the case studies made use of them. The authors specifically looked for cases that demonstrated the use of standardized data formats, but were unsuccessful. For instance, Canam Steel Corp. could benefit from integration if standards such as CIMsteel were adopted by the industry. However, as explained by Thibodeau, “We will start using it if people [engineers] can provide it… Because we are not at the start of the process, somebody has to build the model to the level that we can join and complete the information” [M2]. He adds, “it is going to be quite a challenge to be able to come up with something that everybody will adopt understanding that you may not be able to see what's in it for you because it is the guy down the chain that is going to benefit from it… But at the end it is going to be the owner that is going to be really benefiting and I think that's probably where the drive will have to come from."

Another technology missing from the cases and that holds much potential for the AEC and facility management industry is wireless communication. The use of wireless communications and handheld computers could be an effective way to promote an information culture in the industry. As can be seen in the case studies, web-based document management has progressed faster than integrated information systems (the use of IFC, etc.). The fact that field personnel are always on the run and have to administer multiple documents to track progress and manage changes, will, eventually, bring on a bottom-up need for integrated data. Wireless applications in construction management and facility management could facilitate the transfer of information from sites to office databases. For instance, in the case study [V3], instead of going to the site office to update the progress of an activity over the Internet, this could be done directly on site where the activity is taking place with a wireless PDA (Personal Digital Assistant).

6. GENERAL ISSUES

This section covers some general issues on the use of IT in construction that were identified during the case studies.

Nowadays, *document distribution can all be done electronically*, which means time, paper and cost savings. In addition most communications can be automatically traced. As mentioned by Gagnon, "The document control systems makes sure that we have a proof that each sub has received a copy of the revised drawing" [M3]. The main benefits of using IT are speed in exchange and availability of project information for the entire project team anywhere, anytime [M2]. The system allows the tracking of requests for information (RFIs) and change orders electronically. "If you consider, 30,000 plus drawings, there is a lot of money saved in shipping costs," says Thibodeau [M2].

The *speed at which projects progress* often limits the ability to use IT to its full extent. Thibodeau explains, "Now we are doing more fast track projects plus we are starting to hear flash track projects" [M2]. For instance, Goguen Company Ltd. was unable to implement all the features they wanted to see in a Web-based collaborative project environment because of lack of time [F1]. "Because of the way the industry is working, time is more at the essence of the problem… projects are getting faster all the time and revenues allocated to the various participants on the project are getting smaller all the time," says Thibodeau [M2].

Money is always an issue. *Tight budgets* restrict owners from paying for IT options. Many owners do not provide the funds that allow advances in technological 'extras' [F1]. When a new technology is adopted, important investments need to be made to guarantee everybody access to a computer [V3]. When adding the cost of software to this, not many companies can assume this kind of expenses.

It is *difficult to introduce a new CAD system*. According to a survey conducted at the beginning of 1999, the number of licenses of AutoCAD represented 65% of all CAD licenses owned by the respondents (Rivard 2000). The next contenders were Microstation and Visio with 16% and 11% respectively. Thus, introducing another CAD system in a design project is always difficult. "The biggest obstacle to the use of ArchiCAD is that it is not the industry standard. This especially creates problems while dealing with a clients specifying AutoCAD. For this purpose the company maintained a separate section of AutoCAD professionals," says Miguel Ladouceur [T2].

When Busby + Architects Ltd. considered moving to MicroStation, the cost of the licenses did not allow all the employees to work with the same software. So a few licenses were bought, and old AutoCAD licenses were used to do some more typical 2D drawings. Also, only AutoCAD drawings could be shared with other project parties such as the steel manufacturer or the general contractor because of its de facto industry position. Not all the parties involved in the project had the software platform provided by MicroStation. Having a project that requires two CAD platforms is also troublesome as stated by Maas "there wasn't a person that really knew the way both software work". Furthermore, changing CAD platform is difficult because it is a challenge to find people that can work with the new CAD since universities and institutes mainly provide training for people based on Autodesk tools [V1].

It is costly to *maintain trained personnel* with CAD and IT. Adopting IT approaches may disrupt existing manual processes. Employees need to get used to the new way of doing things [V3]. "It takes six months or so to get somebody well trained in a product," says Goguen [F1]. There is also a rift between young CAD technicians who do not have enough construction experience and the senior personnel who do not have much experience with IT or CAD. "So what's happening is that drawings are produced by CAD personnel who do not have much [construction] experience. They do not understand everything that they are drawing. The person that does, is not working on the drawing and does not really get to see the drawing until it is time for it to be out the door," says Goguen. During construction, workers are not necessarily computer skilled, thus limiting the adoption of IT. It has also been demonstrated that it is not enough to have initial training, rather it is essential to keep providing user support, which indeed adds more cost to the project [V3].

It is difficult to champion IT when *other companies, which lag behind*, reduce the efficiency of the whole endeavor. For instance, Goguen found it difficult to promote a Web-based collaborative environment because: "The contractors haven't really taken to it yet, especially the small contractors. So there would only be a few contractors … with the capability" [F1]. Different contractors have different technological capabilities. Some contractors may have very minimal technological capabilities. Thus, Website access must be given to high-end IT users and data-entry personnel must be available to enter the information from low-end IT users [F2]. Another strategy is to force it on subcontractors. In the case of the E-Commerce building, if subcontractors and suppliers wanted to participate in the project, they had to be able to transmit and receive all documents electronically. "It was a requirement of the contract," says Gagnon [M3]. "You need to encourage subs… Some are reluctant at the beginning, but after a while they all see the benefits of it," adds Gagnon. It is difficult to have every one involved adopt a new technology and new procedures. Gagnon adds, "we had to export our procedures and adapt third parties to the electronic way of functioning." He concludes that the move towards electronic communications needs permanent coaching since some people tend to abandon the new way of working and go back to the old working habits [M3].

On an international project, the same problem is made more complex. When Busby + Architects Ltd. had to collaborate with their Italian counterparts, one of the problems was their level of technology. On "the Italian side, they didn't have the infrastructure in terms of the Internet that we do here. Their download speed was a problem because their office was in an old building, so they didn't have any ASDL access [nor] any cable access," says Maas [V2]. He adds, "at Busby's end, it required [a short] time for uploading the project files while for the Italian end, that would mean a couple of hours of download time" [V2].

Security is a concern on Web applications with regard to handling critical information such as the project budget and schedule. Dion was concerned that potential subcontractors would be able to have access to this critical information before hand, so it was never put on the web [M1].

Regarding *legality*, paper work cannot be completely eliminated because legal documents are needed as "physical evidence with blue ink signatures," says Dion [M1]. Thibodeau explains, "For final drawing approval we still do that based on paper drawings… legally it seems we still have to do that today to get a stamped drawing" [M2]. Once approved drawings are returned, they are scanned and made available online for the rest of the process. "The approved paper documents are stored in a box and never reused again," says Thibodeau. "The only documents that we request to have duplicated or hard copies of are the contracts which are signed originals, all the rest is handled electronically," adds Gagnon [M3].

The implementation of an information system requires a *focus on the construction process* and, equally important, on the work culture rather than on the technology. "Information Technology is a tool. You don't build a solution around a technology… At the end of the day you are building a building," says Bruce Lundrigan [F2]. The technology must adapt to the process.

7. CONCLUSION

Being highly fragmented, the AEC and facility management industry has the potential to greatly benefit from IT because information is the driver of the project activities during all the phases of the building life cycle. The case studies presented here have revealed that several firms across the country are at the cutting edge in their use of IT. These firms are the exception rather than the norm. How can the adoption of these technologies become more wide spread? Slowly, as the statistics show, but inevitably the industry will adopt these technologies. Also, being aware of the benefits from IT, conscientious project owners could encourage project team members to adopt the most suitable ones for their projects. For example, Lemay explains that through the use of IT, "We are now delivering more complex projects much faster than before" [M1]. He adds, "the ultimate beneficiary is the owner because he will be able to get the return from his investment faster". This is why owners play an important role in increasing the adoption of IT in the industry. If owners request the use of IT and are ready to pay for it knowing the compensating benefits, the industry will have to follow. Otherwise, the majority of contractors will wait until they realize that there is a tangible benefit for them. "The message for project team members in the future is: get organized, if you use good technologies you are going to be called," says Dion, Director of Design and Construction of a large development (i.e., owner) company [M1].

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