ELSEVIER

Automation in Construction 13 (2004) 491–506

AUTOMATION IN CONSTRUCTION

www.elsevier.com/locate/autcon

Web-based construction project management systems: how to make them successful?

Pollaphat Nitithamyong*, Mirosław J. Skibniewski

School of Civil Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907-2051, USA

Accepted 27 February 2004

Abstract

This paper describes research conducted at Purdue University on the identification of factors determining success or failure of web-based construction project management systems, particularly through the use of application service providers utilized by construction firms without in-house expertise to develop such systems for exclusive company use.

Keywords: Web-based project management systems; Information technology; Internet; Extranet; Construction; World Wide Web; Internet portal

1. Introduction

The construction industry is fragmented due to the many stakeholders and phases involved in a construction project. This fragmentation has led to well documented problems with communication and information processing and has contributed to the proliferation of adversarial relationships between the parties to a project. This fragmentation is also often seen as one of the major contributors to low productivity in construction.

Information Technology (IT) is now routinely used in the construction industry as a tool to reduce some of the problems generated by fragmentation. The use of IT improves coordination and collaboration between firms participating in a construction project, leading to better communication practices. Its benefits include an increase in the quality of documents and the speed of the work, better financial control and communications, and simpler and faster access to common data as well as a decrease in documentation errors. IT spending in Architecture/Engineering/Construction (A/E/C) firms has increased significantly during the past few years [1], indicating that A/E/C firms are increasing their interests in IT applications to facilitate construction projects.

Among all IT applications, the Internet is the technology that best facilitates a collaborative working environment in a construction project. Walker and Betts [2] postulated that the Internet, and more specifically the World Wide Web (WWW), will be the key to a change in global construction business in the near future and will impact professions, collaboration, and the construction business structure. Its use as a communication medium can help information transfer occur faster and more effectively and enable new opportunities for the development of

* Corresponding author. Tel.: +1-765-742-2082; fax: +1-765-494-0644.

E-mail address: nititham@purdue.edu (P. Nitithamyong).

0926-5805/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.autcon.2004.02.003

distributed systems that can cross organization boundaries and provide a unique opportunity for teamwork and workflow automation. The Web can also overcome the incompatibilities of data formats through smart browsers and servers. Therefore, independent project participants using different hardware platforms can share the same system over the Web [3]. As described in Skibniewski and Abduh [4], the advantages of Web technologies in construction can be broadly categorized into three areas: the support of relevant information services, communication between project participants, and engineering and management computing.

Recently, a concept of how the Web and its associated technologies can be used to manage construction projects has been widely acknowledged by practitioners. This concept is often referred to as a Web-based Project Management System (WPMS)[1] and promises to enhance construction project documentation and control and to revolutionize the way in which a construction project team conducts business. WPMS is an electronic project-management system conducted through the Extranet, which is a private network that uses Internet protocols to transmit information. The system is only accessible by a project team, but team members can be located in different organizations. It basically provides a centralized, commonly accessible, reliable means of transmitting and storing project information [5]. Project information is stored on the server and a standard Web browser is used as a gateway to exchange this information, eliminating geographic and boundary hardware platform differences. Fig. 1 illustrates the basic functional scheme of WPMS [7].

As pointed out by Mead [6], there are four general categories of construction project information that are normally carried out through WPMS: project, design, management, and financial information. Project information includes details about the project, such as project participants, project e-mail directory, project description, and a photo archive of the project's progress. Design information includes any information generated by the design team, such as CAD drawings, specifications, clarifications and changes, and punch lists. Management information is developed by the project manager and includes meeting minutes, submittals and shop drawings, change order status logs, as-built drawings, requests for information (RFIs), requests for quotation (RFQs), contract status logs, safety information, daily logs, and project schedules. Financial information is developed by the accounting staff responsible for the project and includes cash flow, projections, requisition status, general ledger, and contract status reports.

As project information changes, the database on the server can be easily updated with new data. Members of the project team can then access the updated information via a digital user ID and password from remote locations at any time, eliminating the problems that occur in linear communication schemes [8]. Since a closed network is used where no one is allowed to access the system without permission and everyone is identified (through an individual user ID and password), the system can automatically track who has seen what, and what comments or changes if any, they made. It is also possible to introduce a project hierarchy into the system, which allows documents or areas of the project to be restricted to only people at certain levels of responsibility, etc. Hence, the mistakes caused by poor communication and the delays due to the time it takes to move documents and people around for approvals and meetings would be minimized. WPMS is predicted to significantly improve the speed and quality of communication among project participants and promotes collaboration and coordination in construction projects [8,9].

Engineering News Record (ENR) in the United States reports that the number of A/E/C firms using WPMS has risen by 16% within the past 2 years [1]. It is also estimated that the number of A/E/C firms prepared to set up "virtual" project teams by using the WPMS concept is doubling every 6 months. Currently, there are three options in regard to WPMS implementation. The first option is to develop a customized WPMS in-house by hiring either a consulting company or programmers to create a system. The second is to develop a WPMS by purchasing commercial web-enabled packaged software and installing it on

[1] Other names are also used to denote WPMS, including Document Management System, Project Extranet, Project Web, Project Bank, Project Specific Website, Document Pool, Project Information Management System, and Virtual Project.

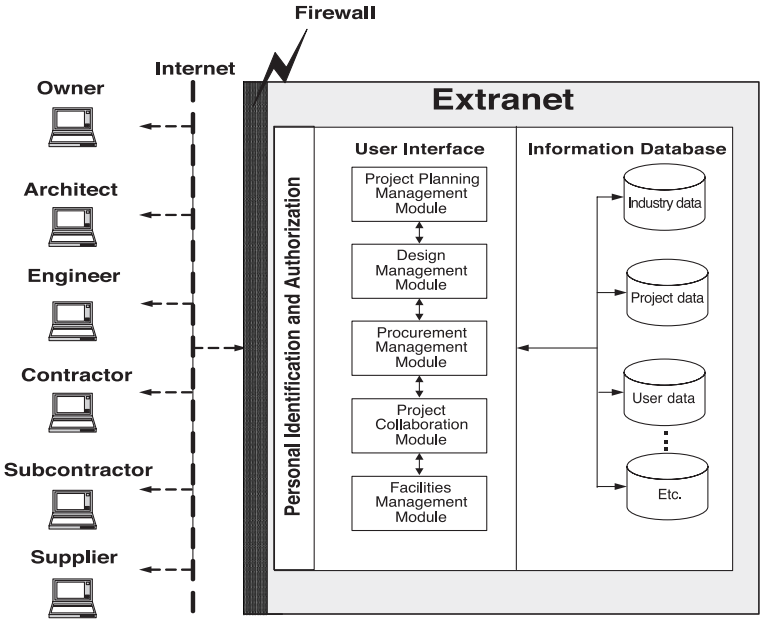

Fig. 1. Functional scheme of WPMS [7].

a company's internal server. Examples of this software include Microsoft Project 2002® from Microsoft®, P3e/c™ and SureTrak™ from Primavera®, Prolog™ Project Pack from Meridian Project Systems™, WebProject™ from Novient®, and Teamflow®7 from CFM. The third is to rent/lease a completely developed WPMS from an Application Service Provider (ASP) for a usage fee, which is normally charged per project, per the amount of computer storage space required, and/or per user. Examples of WPMS developed by ASPs include Buzzsaw™ by Autodesk®, Citadon™, Constructw@re®, ProjectTalk™ by Meridian Project Systems® (MPS), PrimeContract® by Primavera®, Viecon™ by Bentley®, VISTA 2020® by Market Street Technologies®, Projectmates™ by Systemates®, IronSpire®, Unifier™ by Skire®, ProjectGrid.com™, BuildOnline.com®, e-Builder™, BIW Information Channel™, ProjectVillage™, etc.

Among these three options, the third, referred to hereafter as a "Project Management System-Application Service Provider (PM-ASP)", is becoming popular because it requires minimal technical, financial, and human resources to develop and operate [8]. Since PM-ASP is outsourced to an ASP, it requires no effort to develop and maintain the system in-house, involves comparatively low initial investment and overhead cost, and is convenient for keeping up with cutting-edge technology. Therefore, it is a viable solution for a small or mid-sized A/E/C firm that does not have enough resources to maintain an in-house IT department and/or a sophisticated networking infrastructure. In addition, PM-ASP is also capable of performing electronic commerce, such as online bidding and procurement, which are difficult to develop and conduct through an in-house WPMS. The number of A/E/C firms who are turning to PM-ASPs is growing rapidly. It is anticipated that the total spending of A/E/C firms on PM-ASPs would reach US$1 billion by 2004 [10].

Although PM-ASP is a topic of increasing importance to practitioners as well as researchers in construction, it is still relatively new and its optimal styles and extensions of use have not yet been thoroughly investigated. According to Kraker [11], there is still a debate among A/E/C firms whether or not to move permanently to PM-ASPs. Most companies have used PM-ASPs either because their competitors are influencing them or they are being forced to adopt it by their clients [4,9]. Although several ASPs have claimed that their products are the only right solutions to the problems currently facing construction project management, these claims are usu-

ally overestimated or unrealistic, aiming only at marketing purposes.

According to O'Brien [5], the apparent utility of PM-ASPs in construction is still not as attractive as was initially widely expected, and factors such as sociological and people issues require more attention as they greatly impact the system's performance. Industry practitioners must consider not only the technology, but also give equal prominence to processes and people who are involved in the system in order to successfully embrace PM-ASPs and achieve business benefits [12–14]. It is evidenced that 80–90% of IT projects in general do not meet their performance objectives, with the main reasons not related to technical issues [15].

Nevertheless, technically related factors have often gained sole attention while nontechnical factors are considered separately, overlooked, or even ignored completely. Research studies conducted to date still either aim to solve the existing technical problems of PM-ASPs or to introduce some new advanced techniques to improve the current systems, ignoring the fact that technology push is not the only critical success factor for effective implementation of a new technology such as PM-ASP. Unlike other technologies, PM-ASPs are very much concerned with the exchange of information across the project life cycle. Their successful implementation therefore will not only require a state of readiness within one organization, but also within all organizations involved in the construction processes. This makes the successful implementation of PM-ASPs difficult to be planned and managed.

In order for a construction organization to successfully embrace PM-ASPs, factors such as technology, process, people, procurement, legal issues, and knowledge management must be considered equally. Although there have been some studies conducted to identify factors that can foster the successful development and usage of PM-ASP in a construction project, all of them are still based solely on either individual case studies using interview techniques or anecdotal evidence provided by success stories reported in the trade press. There has been no empirical research to date on a large scale conducted on this topic, and it is obvious that a gap still exists in our understanding of what factors, technical and nontechnical, significantly affect the performance of implementing PM-ASPs in construction projects.

As the importance of PM-ASP concept increases, empirical research is needed to identify common factors across the systems and organizations that can lead to the successful implementation of PM-ASPs. The research agenda presented here can help identify these success/failure factors and their levels of impact, leading to productive ways of implementing PM-ASP in a construction project and thereby promote the possibility of successful widespread adoption of PM-ASPs in the construction industry.

In order to implement PM-ASP successfully in a construction project, careful planning and strategies are needed. Several opinions exist regarding PM-ASP implementation, e.g.

1. There are several attributes or measures that might be used to assess the performance of PM-ASP implementation in a construction project.
2. Various factors can contribute to the performance of PM-ASP implementation in a construction project. However, a single factor cannot govern by itself this performance. Interaction of these factors together drives the performance.
3. The success or failure of PM-ASP implementation may or may not directly affect the success of a construction project.

The aforementioned opinions would lead one to raise the following questions regarding PM-ASP implementation in a construction project:

1. What attributes or measures should be used to evaluate the performance of PM-ASP implementation in a construction project?
2. What are the success/failure factors leading to the performance of PM-ASP, and how do they affect its performance?
3. Can these factors, if controlled, ensure the success of PM-ASP implementation in a construction project?
4. What are the relationships, if any, between the success or failure of PM-ASP implementation and construction project success?

This paper is based on research intended to provide answers to all of the aforementioned questions. An

attempt to answer these questions leads to the following objectives:

1. To define a set of measures that can be used to assess the performance of PM-ASP implementation in a construction project.
2. To identify factors leading to the performance of PM-ASP implementation in a construction project.
3. To examine the cause–effect relationships between the identified factors and the performance measures.
4. To use the identified factors and their associated relationships with performance measures for inference, deviation-cause detection, and improvement of PM-ASP implementation in a construction project.
5. To determine if the success or failure of PM-ASP implementation has any effect on the success of a construction project.

The results of this research can be beneficial to A/E/C firms that are using or planning to implement PM-ASPs, and they may shed some light on unexplained deviations in the performance of PM-ASPs. The users of such systems can better understand the important factors that need to be considered to ensure the success of PM-ASP implementation, and the benefits behind changes or improvements in areas of implementation related to critical success factors may increase the chances of successful PM-ASP applications. In addition, the relationship between the success or failure of PM-ASP implementation and the success of a construction project can be better comprehended. Altogether, the results of this research can lead to an improvement of PM-ASP utilization, management, and more widespread acceptance of such systems in the construction industry.

2. Current business models of PM-ASPs

Within the past few years, over 200 ASPs with PM-ASPs focused on the construction industry have appeared on the market [16]. The total capital investment of these ASPs was estimated at US$2.5 billion, and their services and products could be broadly divided into the following three major categories [17].

2.1. Project Collaboration Network (PCN)

PCN focuses on facilitating construction project management. The system aims at sharing project-specific documents, communications, and workflow and serves as a repository for documents or as an online document management system for a project team. The common services include backing up files daily, keeping a document revision history, and tracking who accesses files. PCN also offers online document viewing, online markup, and plotting. Various members of the construction team can upload or download drawings, and construction documents through PCN.

PCN is normally hosted on an ASP's server. However, an A/E/C firm with multiple projects may choose to buy a PCN solution and install it on the company's internal servers. The monthly cost for using PCN usually depends on the intensity of the usage of the database and/or the number of registered

Table 1
Examples of PCNs catering to the construction industry

PCN service	Company	URL
ActiveProject™	Framework Technologies	www.activeproject.com
Buzzsaw™	Autodesk	www.buzzsaw.com
BuildOnline™	BuildOnline.com	www.buildonline.com
CAM Console™	LoadSpring Solutions	www.loadspring.com
Citadon CW™	Citadon	www.citadon.com
Constructw@re™	Constructware.com	www.constructware.com
e-Builder™	MP Interactive	www.e-builder.net
Edificium	Edificium.com	www.edificium.com
MH2.com	MH2 Technologies	www.mh2.com
OnlineBuildings™	OnlineBuildings.com	www.onlinebuilding.com
Paragon™	Vianovus.com	www.vianovus.com
ProjectEDGE™	Edgewater Services	www.projectedge.com
ProjectGrid.com	ProjectGrid.com	www.projectgrid.com
Projectmates™	Systemates	www.projectmates.com
ProjectSolve®	Company 39	www.projectsolve.com
ProjectTalk™	Meridian Project Systems	www.projecttalk.com
ProjectVillage™	ProjectVillage.com	www.projectvillage.com
Tririga IBS™	Tririga	www.tririga.com
Viecon™	Bentley Systems	www.viecon.com
Vista 2000™	Market Street Technologies	www.marketstreet.com
Web4Engineers™	Web4	www.web4engineers.com
4Projects™	4Projects	www.4projects.com

Table 2
Examples of nonspecific PCNs

PCN service	Company	URL
@VIEW[net]	Atview	www.atview.com
eProject Enterprise™	eProject	www.eproject.com
Intranets.com	Intranets.com	www.intranets.com
Intra.net™	Inclusion Technologies	www.inclusion.net
Project InVision.NET™	Project InVision International	www.smecorporation.com
ProjectShare DNA™	ProjectShare.com	www.projectshare.com
Share-A-Space™	Eurostep Group	www.share-a-space.com
WebWorkZone™	SiteScape	www.sitescape.com
WelcomHome™	Welcom.com	www.welcom.com

users. Table 1 illustrates some currently available PCNs catering to the construction industry.

Besides the PCNs shown in Table 1, there are also some PCNs which are not tailored specifically for the construction industry, but A/E/C firms may use these services/products as well. Table 2 illustrates some examples of these nonspecific PCNs.

2.2. Project Information Portal (PIP)

PIP serves mainly the general information needs for the participants in a construction project. This information includes codes and permits, economic trends, product information, cost data, and project planning information that a project team might use throughout the life of a construction project. Most PIPs offer free services to members since their major profits come from advertising, while others charge a monthly subscription fee. Table 3 illustrates examples of PIP currently available for the construction industry.

2.3. Project Procurement Exchange (PPE)

PPE aims to streamline the procurement cycle of construction materials and services. The system provides electronic bidding and procurement services, which generally allow users to view online catalogs of products and services, transmit RFQs, exchange cost-related data, review work packages, and conduct bidding and procurement online. Table 4 illustrates some examples of PPE currently available for the construction industry.

Table 4
Examples of PPEs for the construction industry

PPE service	Company	URL
BuildPoint.com	BuildPoint.com	www.buildpoint.com
Buildscape™	Buildscape.com	www.buildscape.com
BidA/E/C.com	BidA/E/C.com	www.bidaec.com
BidExpress.com	Contractors Online	www.bidexpress.com
BidHost™	eBid Systems	www.ebidsystems.com
Contractors eSource™	Contractors eSource	www.contractorsesource.com
Cprojects.com	Cprojects.com	www.cprojects.com
eu-supply.com	eu-supply.com	www.eu-supply.com
PurchasePro™	PurchasePro.com	www.purchasepro.com
TradePower™	TradePower	www.trade-power.com

Table 3
Examples of PIPs for the construction industry

PIP service	Company	URL
Akropolis.net	Akropolis	www.akropolis.net
4specs	4specs.com	www.4specs.com
Biw.co.uk	BIW Technologies	www.biw.co.uk
BuildersPlanet.com	BuildersPlanet.com	www.buildersplanet.com
Building.com	Building.com	www.building.com
Buildingonline.com	Buildingonline.com	www.buildingonline.com
CMD First Source™	CMD First Source.com	www.cmdfirstsource.com
DesignArchitecture	DesignArchitecture.com	www.designarchitecture.com
e-idc.com	e-idc.com	www.e-idc.com
Handyman Online	Handyman Online.com	www.handymanonline.com
HomePro.com	HomePro.com	www.homepro.com
ImproveNet™	ImproveNet.com	www.improvenet.com
NationalContractors.com	NationalContractors.com	www.nationalcontractors.com
StartMyHome.com	StartMyHome.com	www.startmyhome.com

Currently, several ASPs are starting to use the above three major categories collaboratively in their business models. For example, *Ironspire*™ (www.ironspire.com), Bricnets® (www.bricsnet.com), and BIW® Technologies (www.biwtech.com) have integrated PCN and PIP in their services. Construction *Sweets*™ (www.sweets.construction.com) has integrated PIP and PPE. *HomeSphere*™ (www.homesphere.com) has integrated PCN and PPE. Some of them even provide a "Full-Service Portal" having all features offered by PCN, PIP, and PPE, which means that team members can track and manage project documents online, communicate and share information, search online catalogs for needed resources, and conduct electronic bidding and procurement. The goal of full-service portals is to satisfy every project-related need of the supply chain in a construction project [18]. Nevertheless, features provided by full-service portals are still not fully integrated in one service package, and a company normally needs to pay additional fees to use all of the available features. Table 5 illustrates some examples of full-service portals currently available for the construction industry.

According to a survey conducted by ENR, 80% of contractors and owners still use PM-ASP mainly for project collaborations, 25% for online purchase and sell products, 17% for bidding jobs online, and 13% for negotiating contracts. Another survey also showed that no single dominant PM-ASP exists in the A/E/C market [19]. Architecture and engineering firms are most likely to use online project collaboration, followed by general contractors, owners, and subcontractors, respectively [20]. Nevertheless, as more dot-com companies target the construction industry, it is predicted that US$141 billion, or 11%, of the US construction industry spending will be conducted online by 2004 [21].

Table 5
Examples of full-service portals for the construction industry

Portal service	Company	URL
Causeway Solutions	Causeway Technologies	www.causeway-tech.com
CX™ Solutions	Aconex	www.aconex.com
e-Manage Net™	Microlar Systems Limited	www.microlar.com
PrimeContract™	Primavera Systems	www.primecontract.com

3. Current features of PM-ASPs

Depending on the selected business model, the features supported by PM-ASP usually vary, but a list of current features that can be supported by PM-ASPs follows. However, considering the exponential rate of technological changes, this list may not be exhaustive as most ASPs are constantly trying to reshape themselves to meet customer demands, i.e., a feature offered one day may be changed, modified, or not available the next day. O'Brien [5] suggested that it is important for A/E/C firms to have a specific feature and think through how this feature would interact with the job tasks of project team members.

3.1. Document management

This feature establishes a single location to store general project-related files, such as project photos, contracts, drawings, specifications, cost data, etc. It allows team members to manage, track, and organize these files in a central location.

3.2. Project workflow

This feature allows team members to collaborate electronically using RFIs, change orders, field notes, correspondence, submittals, punch lists, daily logs, and standard or customized forms.

3.3. Project directory

This feature stores general information (phone number, address, and e-mail) of project team members in a central directory. Therefore, specific information for each project participant can be easily retrieved when needed.

3.4. Central logs and revision control

This feature allows team members to track who accessed files or downloaded a particular document, as well as when the file was edited and uploaded to the system. It also includes the use of digital signatures to identify and verify an individual before entering the data or transmitting information.

3.5. Advanced searching

This feature allows team members to find documents or specific details within documents through the entire log. This is the key feature that enables users to locate documents more easily, compared with situations where files are located in different offices, on different servers, or scattered about on local computers.

3.6. Conferencing and white-boarding

This feature allows team members to share applications and documents concurrently using the virtual whiteboard and to apply comments online. Theoretically, a whiteboard and notes could also be saved and attached to other workflow forms such as RFIs.

3.7. Online threaded discussion

This feature is a communication tool similar to a newsgroup and e-mail that allows a ''threaded'' discussion to take place online. It provides an open forum that displays a sequential record of messages and responses about a particular topic. Team members post questions, responses, and comments and have a permanent record of the discussions and decision process surrounding an issue. For a sensitive topic, it can also be protected by a secured password.

3.8. Schedule and calendar

The calendar feature allows team members to coordinate project events or meetings in a centralized agenda. Team members can then copy events or meetings to their standard software, such as Microsoft® *Outlook* and Eudora®. The schedule feature allows team members to create project schedules online or to convert project schedules created by standard scheduling tools, i.e., Microsoft® *Project*, *Primavera* P3e/c™, and *SureTrak*™ to an online working schedule. A view of the bar chart and the capability of modifying information and assigning resources can also be done using the schedule feature. Alerts with direct links to the task in question are provided to team members having overdue items. The schedule feature can also be integrated with the calendar feature to quickly view milestones at a glance.

Table 6
Current features of selected PM-ASPs

Type of PM-ASP	Example products	Common features							
		Document management	Project workflow	Project directory	Central logs and revision control	Advanced searching	Conferencing and white boarding	Threaded discussion	Schedule and calendar
Project collaboration network (PCN)	Buzzsaw™	×	×	×	×	×	×	×	
	Citadon™	×	×	×	×	×	×	×	×
	Constructw@re™	×	×	×	×	×		×	×
	e-Builder™	×	×	×	×	×	×	×	×
	Project Talk™	×	×	×	×	×	×	×	×
Project Information Portal (PIP)	4Specs.com					×			
	Biw.co.uk					×			
	BuildingOnline.com					×			
Project Procurement Exchange (PPE)	BidExpress.com								
	BuildPoint.com					×			
	BidA/E/C.com					×			
PCN + PIP	BIW Technologies	×	×	×	×	×	×	×	×
	IronSpire JobSite™	×	×	×	×	×		×	×
	Bricnets®	×	×	×	×	×		×	×
PCN + PPE	HomeSphere™	×	×	×	×	×		×	
PIP + PPE	ConstructionSweets™					×			
Full Service Portals (PCN + PIP + PPE)	PrimeContract™	×	×	×	×	×		×	
	Causeway Solutions	×	×	×	×	×	×	×	×
	CX™	×	×	×	×	×		×	

3.9. Project camera

This feature allows a project team to monitor construction sites remotely using web-based cameras and transfer live photos of the job sites directly to their computers. These photos can then be used to share progress, resolve issues and questions, and minimize site visits.

3.10. File conversion

This feature supports file conversion to displayable formats to be shown through a web browser. It may also enable marking and adding notes for these converted files.

3.11. Printing service

This feature provides the ability to make hardcopy prints of online files, such as construction drawings and specifications and allows team members to send print orders to local reprographic printing centers. Most ASPs now offer tools to create print-ready letter-size and D-size hardcopies.

3.12. Website customization

This feature allows team members to modestly customize the browser interface to better suit the management needs. Users can lay out the project environmental tabs and menus and add a company logo to the interface.

3.13. Offline access

This feature allows team members to access the project databases when offline. It ensures that all participants can reliably access key data and get their job done, even when the Internet connection is slow, unreliable, or not available.

3.14. Messaging outside the system

This feature allows team members to send project information or files to an important participant, i.e., an owner's representative, who is not connected to the Internet, by the use of fax, Internet e-mail, or voice mail/pager notification to offline participants.

									Expanded features	
Project camera	File conversion	Printing service	Website customization	Offline access	Messaging outside the system	Wireless integration	Archiving of project information	Information service	Financial service	e-Bidding and procurement
×	×	×			×		×			
	×		×	×	×		×			
	×			×	×	×	×			
×	×		×	×	×	×	×			
×	×			×	×		×			
								×		
					×			×	×	
					×			×		
		×								×
										×
		×								×
×	×		×	×	×		×	×		
×	×			×	×	×	×	×		
	×		×				×	×		
×	×			×			×			×
					×			×	×	×
	×		×		×		×	×		×
	×	×	×	×	×	×	×	×	×	×
	×	×		×	×	×	×	×		×

3.15. Wireless integration

This feature allows team members to use wireless devices such as pagers, mobile phones, and Personal Digital Assistants (PDAs) to access the project information database. It may also allow team members to input or edit project information via wireless devices and transfer this information back to the centralized servers. This feature is very well suited for onsite personnel.

3.16. Archiving of project information

This feature allows a project team to copy the entire project database to a set of compact discs after the completion of a construction project, creating a comprehensive record of the entire project website with its associated databases and transaction logs. A project team thus can have all project records necessary for any disputes and the future operation and maintenance of the facility.

3.17. Information service

This feature includes product catalogs, a discussion forum, resource libraries, predefined links, and search engines. It basically helps team members locate needed resources and information, such as local consulting services and suppliers.

3.18. Financial service

It is normal in a construction project that a project team must secure financing before the project starts. This feature provides lenders the ability to collaborate with borrowers and suppliers in the sourcing, underwriting, closing servicing, analyzing, and securing of project loans.

3.19. E-bidding and procurement

Bidding and procurement processes typically involve issuing RFQs and responding to RFIs. This feature streamlines bidding and procurement processes associated with the purchases of equipment, specialized materials, and services. Team members can issue RFQs, track all new and pending transactions, review and compare bids received from material or service suppliers, and conduct e-procurement online. It may also facilitate transactions that require an exchange of information, such as design documents, drawings, and specifications.

Table 6 exhibits the features of some currently available PM-ASPs for the construction industry. The PM-ASPs listed in this table were selected as examples only, and the contents shown in the table may not reflect the current status of each PM-ASP.

4. Potential benefits of PM-ASPs

PM-ASPs offer A/E/C firms numerous advantages over the current inter-organizational information infrastructure by providing access to project data and communication that is platform and application-independent. All that is required is Internet access and a Web browser. PM-ASPs are also location-independent since the systems can be accessed wherever there is Internet access and a Web browser. Communication can be either synchronous or asynchronous, and individuals can access project database anytime or multiple team members can collaborate in real-time.

In addition to enhancing communication and access to project information, PM-ASPs also provide several potential advantages over in-house WPMS. Following are some of the advantages repeatedly cited in literature.

4.1. Cost advantage

PM-ASPs use numerous centralized application servers and data warehouses instead of concentrating power in the desktop computer as is currently done. In this case, what is left on the user's desktop is a stripped-down network computer that communicates with applications and data servers via the network. Experts predict that individuals and corporations will own very minimal software and will rent most of what they need from Internet Service Providers (ISPs) and other network operators [22]. Therefore, PM-ASPs potentially provide savings in time and resources compared to in-house solutions, which can be costly, time consuming, and maintenance-intensive, and many require a high degree of expertise by the system administrator and user to implement. A study of Internet-based groupware cited a return on investment

ratio of greater than 1000 to 1 [23]. The savings of using PM-ASPs in the construction industry could also be at a similar magnitude.

4.2. Outsourcing advantage

Although it is possible to develop an in-house WPMS that would have almost the same functionality as PM-ASPs, there are many arguments against it. McFarlan [24] presented a model that helps firms understand when it is advantageous to outsource IT services, linking the IT outsourcing decision to the strategic impact of the existing information systems and the portfolio of applications the firm has under development. In highly competitive, transaction-intensive, knowledge-based industries like banking and insurance, both the information systems and the development portfolio play what McFarlan categorizes as a strategic role. Outsourcing such a core process can lead to loss of critical competitive skills and of control of important proprietary information. On the other hand, in industries like large-scale process manufacturing or, in this case, the construction industry, IT plays only a support role. It is much more of a commodity and hence, although necessary, it is not central to the firm's competitive position. By this reasoning, many computing functions in the construction industry are good candidates for outsourcing.

There are several advantages to outsourcing portions of construction industry computing that mainly relate to scale. Small A/E/C firms, which make up the majority of the construction industry, are able to take advantage of sophisticated communications and computing software that they would otherwise be unable to afford. Even larger firms in the construction industry may have difficulty justifying the relatively high investment required to develop the functionality of WPMS. A number of currently available PM-ASPs are actually spin-offs from design and construction firms that saw an opportunity to take their in-house computing systems to scale.

4.3. Competition among IT professionals

The market for skilled programmers and IT professionals has become extremely competitive in the past several years. Recruiting and retaining high quality IT personnel is increasingly difficult in all industries at a time when the rapid expansion of the Internet and the high-tech industry has created an extremely high demand for developers and other IT professionals. A report by the U.S. Department of Commerce predicted a shortage of IT workers between 1995 and 2005 [25].

In the construction industry, executives acknowledge that the market for IT workers has become ultra-competitive. They point to technology as magnet for young people [26]. Some A/E/C firms found that they must make a larger investment in IT to attract and retain talented young professionals. However, it will continue to be relatively difficult and expensive for A/E/C firms to attract the best talent away from cutting-edge high-tech companies. PM-ASP providers, on the other hand, have better access to the latest technological developments in software and hardware, and more importantly, have better access to high-quality system designers and programmers.

4.4. ASP's competition

A/E/C firms will also benefit from the intense competition in the PM-ASP market. As PM-ASP providers attempt to differentiate their products from those of their competitors, they continue to expand their internal feature packages and to develop linkages to important external software. These upgrades are incorporated on the PM-ASP provider's central server, giving the client immediate access to new features with no need to purchase and install new versions or upgrades. Björk [13] postulated that competition among PM-ASP providers will continue to drive down costs and enhance product quality and performance, translating into value for the construction industry.

5. Potential barriers to PM-ASP implementation

Besides the benefits that PM-ASPs may provide, some important barriers to implementation still exist and should not be overlooked. These barriers need to be addressed in order to increase public confidence in adopting PM-ASPs in construction projects. The literature shows that these barriers include a wide range of issues that can be summarized as follows.

5.1. Difficulties in quantifying costs and benefits

It is difficult to persuade every organization participating in a construction project to make the necessary level of investment to fully implement a PM-ASP, which is due in part to the fact that there is still no reliable data on the economic impact of PM-ASPs for projects or firms [27]. The temporary nature of relationships in a construction project also provides little or nor incentive for investing in innovative technologies [28]. A/E/C firms have been slow to commit to the adoption of PM-ASPs on the mere suspicion that PM-ASPs reduce cost or improve overall project performance. Many of them are still taking a ''wait and see'' approach to the use of PM-ASPs until more definitive cost and benefit data are available [29,30].

5.2. System reliability

Ideally, a PM-ASP should be available to users at all time to ensure its high reliability. However, this is rarely the case [31]. When servers are down, users become disconnected and unable to work online. Data can also be lost if the system is not backed up or is improperly housed. With hundreds of new ventures competing for the industry's attention, a PM-ASP provider may not be able to adequately take care of users' needs or could even go out of business, leaving users without recourse in the middle of a project.

5.3. System security

System security is probably the most important issue considered by A/E/C firms when implementing PM-ASPs and e-commerce [28,31]. This issue is well founded, especially in the wake of recent, highly publicized ''hacking'' break-ins. A high-security PM-ASP is a system with low or no chance of unauthorized users or competitors accessing the system and data. Although most PM-ASPs currently employ a ''user name and password'' scheme to protect an unauthorized access to their sites, this scheme is too simple and still inadequate in satisfying the security requirements of electronic transactions in construction projects. Users still rely mostly on mutual trust between parties, as well as paper-based in parallel when using this scheme [32]. This inadequacy has prevented the creation of complete confidence in the construction industry to adopt PM-ASPs [33].

5.4. Legal issues of electronic transactions

Although the existing legal environment may provide essentially clear guidelines for construction practitioners to manage a contract in a paper-based environment, new collaborative tools such as PM-ASPs change the work method, making legal responsibilities in this new environment unclear [5]. In fact, an online contract enabled by PM-ASPs is still a new approach that may pose risks, particularly in the area of jurisdiction and enforcement. Since the Internet marketplace is global, e-commerce participants potentially are subjecting themselves to the laws of distant states and countries. A simple solution is to use the forum selection and choice of law provisions in online contracts. However, there is no guarantee that a court will always enforce such language [31].

5.5. Lack of software interoperability

An important inhibitor to the adoption of PM-ASPs is the technical difficulties caused by the incompatibility of systems [17,28,34]. Companies participating in a construction project usually deploy different software programs to manage their enterprises, resulting in inter-organizational incompatibility and creating an inherent barrier to information sharing when implementing a PM-ASP. Although this problem has been overcome by the adoption of common standards for the construction industry, such as IFC and aecXML, incompatibility often remains a problem in international transactions [35]. It is expected that a widespread adoption of PM-ASPs will be more likely when universal standards are defined and users are able to seamlessly share data between multiple systems.

5.6. Data ownership after project completion

The actual ownership and control of data after project completion is of considerable importance when implementing PM-ASPs. Although most ASPs allow project owners to archive the entire project record on CD-ROM after project comple-

tion, there is still debate on who should get copies of the project record and what information should be included or excluded from each party's version [31].

5.7. Internet access and bandwidth problems

Internet access is a prerequisite to the use of PM-ASPs. Although some government agencies and large A/E/C firms may have a high percentage of employees having access to the Internet, most small and medium A/E/C firms still have little or no access. Moreover, most A/E/C firms still use dial-up modems to access PM-ASPs. A dial-up connection may be adequate to simple electronic communications such as e-mail, Internet Relay Chat (IRC), and newsgroup; however, it is not appropriate to convey large and complex project information, i.e., CAD drawings, or to process requests for large amounts of information online [36]. Although high-speed Internet connections (Digital Subscriber Lines (DSL), Integrated Services Digital Network lines (ISDN), cable modem, T1 or T3 leased lines, and wireless Internet access) may be available for A/E/C firms to use, these connections are still relatively expensive and may not be available in a particular geographic.

In addition to the above problems, several organizational or "people" barriers also significantly hinder the success of PM-ASP adoption. The literature repeatedly reports that such organizational barriers encountered in IT development projects are even more difficult to overcome than any other barriers [5,15,32,37–39]. Some of the organizational barriers specific to PM-ASP implementation are as follows.

5.8. Resistance to change

An information system implementation can cause considerable organizational change that people tend to resist [40]. Practitioners in the construction industry generally resist change and need to know how to use a PM-ASP effectively or how the system can facilitate their work tasks. They usually require a road map to integrate a PM-ASP into their work prior to their acceptance of a new system. The likelihood of this resistance increases with the scope and magnitude of the changes that the system creates [41].

5.9. Password barrier

Most PM-ASPs use password protection as a key to allow users to access project information database. However, it is impractical to give everyone a password. Therefore, a project team needs to define individuals who should have access to the system. This defined use creates a problem such that a system will not be used by all project members. Some participants who have access to the service may need to employ dual systems of electronic and traditional means of communication in order to deal with project members who do not have access to the system. This duplicative process may significantly undermine the effectiveness of PM-ASPs.

5.10. Density of communication channels

The density of communication channels in a construction project poses challenges for the use of a PM-ASP. Since other channels exist, it is easy for a project team member to bypass a PM-ASP with more familiar technologies such as a telephone, a mobile phone, a fax machine, and a beeper.

5.11. Team tools and problems of something for everyone

Most PM-ASPs have not been specifically designed to interact with the standard tasks of individual project team members. As a tool for the team, a PM-ASP offers a little something for everyone but is not a complete communications and information handling solution for anyone. This makes it harder for team members to integrate the system into their work and helps to explain the lack of creativity exhibited by users.

5.12. Collaborative maturity

Collaborative maturity represents the level to which team members are willing to work together and share information and experience to make the project succeed. It is suggested that the collaborative maturity of a team varies greatly. Currently, PM-ASPs are more useful to a team that possesses a high level of collaborative maturity. However, practitioners in the construction industry are still uncomfortable giv-

ing power away even within a team with a high degree of collaborative maturity.

6. The future of PM-ASPs

As demonstrated in the previous sections, PM-ASPs offer substantial benefits to A/E/C firms, but their implementation is still hindered by many barriers. Thus, an important question now is "What will be the future of PM-ASPs in the construction industry?".

The literature points out a trend toward the future market of PM-ASPs that is believed will be realized within the next few years. This trend can be summarized as follows.

- The number of ASPs will decrease.
- A standard for features will be established.
- PM-ASPs will be easy to use and more integrated with other systems than today.
- The price will decrease.
- Data security will become a major concern.

In terms of future use, Unger [42] suggested that the time frame for PM-ASP adoption in the construction industry could be explained using Geoffrey Moore's technology adoption curve as shown in Fig. 2. Between 1998 and the end of 2001, the industry's innovators and early adopters tested PM-ASPs and found them to be of significant benefit. From 2002 to the end of 2003, well-known construction companies started using PM-ASP on their major projects and began pushing PM-ASPs out to their business partners. Meanwhile, owners who had seen the results also started adopting PM-ASPs themselves and began to specify the use of PM-ASPs in their contracts. Starting from 2004, small and medium A/E/C firms who can be regarded as a late majority will clearly see the benefits of PM-ASPs and will use PM-ASPs in all of their projects. A truly transformational new era of productivity in the construction industry will begin to unfold in this period.

7. Summary and conclusions

This paper presented the state-of-the-art of PM-ASPs for the construction industry, the current business models of PM-ASPs, and their supported features. Examples of systems currently available on the market were demonstrated. The potential benefits and impediments of PM-ASP implementation were also discussed, followed by a review of trends towards the future of PM-ASPs and some existing research related to PM-ASPs conducted by academia.

It can be concluded that PM-ASPs present significant benefits to the construction industry, but their successful implementation is still hindered by barriers, for the most part nontechnical. Yet, research conducted to date still either aims to solve the existing technical problems of PM-ASPs or to introduce some new advanced techniques to improve the systems. Most of them ignore that technology push is not the only critical success factor for effective implementation of a new technology such as PM-ASP. Unlike other technologies, PM-ASPs are very much concerned with the exchange of information across the project life cycle, and their successful implementation therefore will not only require a state of readiness within one organization but also within all organizations involved in the

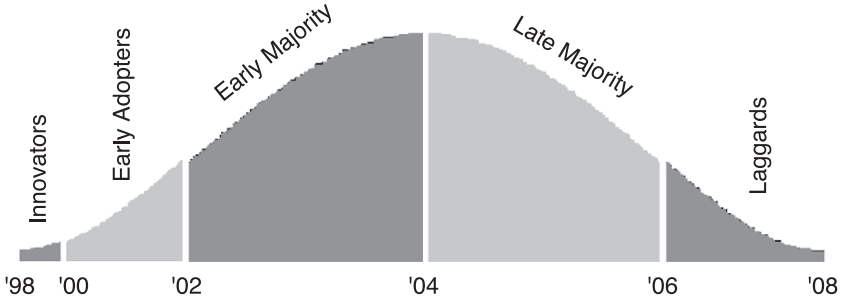

Fig. 2. Geoffrey Moore's technology adoption curve.

construction processes, which makes the successful implementation of PM-ASPs difficult to be planned and managed.

In order for the construction industry to successfully embrace PM-ASPs, many factors such as technology, process, people, procurement, legal issues, and knowledge management must be considered equally. Although there have been some studies conducted to identify factors that can foster the successful development and usage of PM-ASPs, all of them are still based on either individual case studies using interview techniques or anecdotal evidence provided by success stories reported in the trade press. There has been no empirical research on a large scale conducted on this topic. As the importance of PM-ASP concept increases, the authors have completed a major research effort to identify common factors across the systems and organizations that can influence the success/failure of PM-ASP implementation efforts. The results of this research will be made available in subsequent publications.

References

[1] M.C. Hurtado, New survey points to spending growth, Engineering News Record, vol. 246 (21), McGraw-Hill, New York, USA, 2003, pp. 21.

[2] D. Walker, M. Betts, Information technology foresight: the future application of the world wide web in construction, Proceedings of the CIB W78, IT for Construction Process Reengineering, Cairns, Australia, July 1997.

[3] E.M. Rojas, A.D. Songer, Web-centric systems: a new paradigm for collaboration engineering, Journal of Management in Engineering, vol. 15 (1), ASCE, New York, USA, 1999, pp. 39–45.

[4] M.J. Skibniewski, M. Abduh, Web-based project management for construction: search for utility assessment tools, Invited Keynote Paper, Proceedings of INCITE 2000, Hong Kong Polytechnic University, 17–19 January.

[5] W.J. O'Brien, Implementing issues in project web sites: a practitioner's viewpoint, Journal of Management in Engineering, vol. 16 (3), ASCE, New York, USA, 2000, pp. 34–39.

[6] S. Mead, Project-specific intranets for construction teams, Project Management Journal, vol. 28 (3), Project Management Institute, Pennsylvania, USA, 1997, pp. 44–51.

[7] M.J. Skibniewski, P. Nitithamyong, Web-based construction project management systems: practical advantages and disadvantages, Invited Keynote Paper, Proceedings of 4th International Conference on Construction Project Management: Remarking Construction in the Knowledge-Based Economy, Nanyang Technological University, Singapore, 4–5 March, 2004.

[8] T. Thorpe, S. Mead, Project-specific web sites: friend or foe? Journal of Construction Engineering and Management, vol. 127 (5), ASCE, New York, USA, 2001, pp. 406–413.

[9] P. Doherty, Site seeing, Civil Engineering, vol. 69 (5), ASCE, New York, USA, 1999, pp. 38–41.

[10] J.H. Follett, Build online, and they will come, CNR (2001 March 29).

[11] J.M. Kraker, E-construction project management—firms jockey for the lead in the race to go on line, Engineering News Record, vol. 245 (12), McGraw-Hill, New York, USA, 2000, pp. 65.

[12] M. Alshawi, B. Ingirige, Web-Based Project Management, A Report on Web-Enabled Project Management, University of Salford, UK, 2002, http://www.extranetnews.com/web%20enabled%20project%20managment.pdf, as viewed on November 15, 2002.

[13] B.-C. Björk, The impact of electronic document management on construction information management, Proceedings of the CIB W78 Workshop on Distributing Knowledge in Building, the Aarhus School of Architecture, Denmark, June 12–14, 2002.

[14] M. Alshawi, B. Ingirige, Web-enabled project management: an emerging paradigm in construction, Automation in Construction, vol. 12 (4), Elsevier, New York, USA, 2003, pp. 349–364.

[15] C. Clegg, C. Axtell, L. Damodaran, B. Farbey, R. Hull, R. Jones, J. Nicholls, R. Sell, C. Tomlinson, Information technology: a study of performance and the role of human and organizational factors, Ergonomics, vol. 40 (9), Taylor & Francis, London, UK, 1997, pp. 851–871.

[16] C. Cyon Research, The List, The Extranet News, http://www.extranetnews.com/the_list/thelist_keys.htm, as viewed on October 30, 2003.

[17] J. Bryant, J. Petre, Project Management in the Construction Industry, White Paper for the Construction Industry Advisory Council (CIAC) (http://archnt2.tamu.edu/contech/finalj/proj_man.html), as viewed on November 15, 2002 (2000).

[18] B. Burchard, AEC project management online, CADalyst, (2001 July) 13–19.

[19] R. Korman, T. Illia, Industry dot-coms march to slower, steadier pace, Engineering News Record, vol. 246 (23), McGraw-Hill, New York, USA, 2001, pp. 36.

[20] J. Wesek, V. Cottrez, P. Landler, A Benefits Analysis of Online Project Collaboration Tools Within the Architecture, Engineering, and Construction Industry, A White Paper Reported by PricewaterhouseCoopers (http://www.buzzsaw.com/content/customers/white_papers/roi_pwc.pdf), as viewed on November 15, 2002 (2000).

[21] B. Tedeschi, Construction heads into the internet age, New York Times (2000 February 21) C1.

[22] T. Eisenmann, S. Pothen, Application Service Providers, A class note prepared for Harvard Business School, Document number 9-801-310, January 8 (2001).

[23] I. Campbell, The Intranet: Slashing the Cost of Business, International Data, California, 1997.

[24] W. McFarlan, Information technology changes the way you compete, Harvard Business Review (1994 May–June) pp. 98–103 (Reprint No. 84308).
[25] A. Pincus, America's New Deficit: The Shortage of Information Technology Workers, U.S. Department of Commerce, Washington, DC, 1997.
[26] M. Phair, Collaborative systems move closer, Engineering News Record, vol. 241 (2), McGraw-Hill, New York, USA, 1998, pp. 42–43.
[27] W. Back, K. Moreau, Information management strategies for project management, Project Management Journal, vol. 32 (1), Project Management Institute, Pennsylvania, USA, 2001, pp. 10–19.
[28] C.J. Anumba, K. Ruikarm, Electronic commerce in construction—trends and prospects, Automation in Construction, vol. 11 (3), Elsevier, New York, USA, 2002, pp. 265–275.
[29] P.S. Chinowsky, R.E. Goodman, Managing interdisciplinary project teams through the web, Journal of Universal Computer Science, vol. 2 (9), 1996, pp. 597–609.
[30] P. Bishop, Overview of e-construction project management, New Civil Engineer Plus, NCE, London, UK, 2001 June 5.
[31] P.W. Berning, S. Coyne, E-commerce and the construction industry: the revolution is here, Industry Reports Newsletters provided by the Construction Web Links (http://www.constructionweblinks.com/Resources/Industry_Reports_Newsletters/Oct_2_2000/e-commerce.htm), as viewed on April 15, 2004 (2000).
[32] F. Peña-Mora, K.K. Choudary, Web-centric framework for secure and legally binding electronic transactions in large-scale A/E/C projects, Journal of Computing in Civil Engineering, vol. 15 (4), ASCE, New York, USA, 2001, pp. 248–258.
[33] W.G. Krizan, eConstruction disputes: liability disclaimers lead way as digital age issues weigh in, Engineering News Record, vol. 246 (8), McGraw-Hill, 2001, pp. 41–45.
[34] O.O. Ugwu, C.J. Aumba, J.M. Kamara, Integration of customer requirements with products and services on the internet, Proceedings of the UK National Conference on Objects and Integration for Architecture, Engineering, and Construction, Watford, UK, March 13–14, 2000, ISBN 1 86081 377 1, CRC Publishers, pp. 40–49.
[35] M. Morell, J. Ezingeard, Revisiting adoption factors of inter-organizational information systems in SMEs, Logistics Information Management, vol. 15 (1), Emerald, West Yorkshire, UK, 2002, pp. 46–57.
[36] W.J. Angelo, Broadband casts broad net over construction jobsites, Engineering News Record, vol. 246 (23), McGraw-Hill, New York, USA, 2001, pp. 41.
[37] M.J. Earl, Management Strategies for Information Technology, Prentice-Hall, Hemel Hempstead, Herts, 1989.
[38] K. Irani, J.-N. Ezingeard, R.J. Grieve, Integrating the costs of an IT/IS infrastructure into the investment decision making process, The International Journal of Technological Innovation, Entrepreneurship and Technology Management (Technovation), vol. 17, 1997, pp. 695–706.
[39] Z. Irani, J.-N. Ezingeard, R.J. Grieve, Investment justification of information technology in manufacturing, International Journal of Computer Applications in Technology, vol. 12, 1999, pp. 90–101.
[40] M.L. Markus, Power, politics, and MIS implementation, Communications of the ACM, vol. 26 (6), Association for Computing Machinery, New York, USA, 1983, pp. 430–444.
[41] P. Tait, I. Vessey, The effect of user involvement on system success: a contingency approach, MIS Quarterly, vol. 12 (1), Society for Management Information Systems, Minnesota, USA, 1988, pp. 91–108.
[42] Unger, The trend toward an internet-based communication standard in the A/E/C industry, A White Paper Provided by Constructware (http://www.constructware.com/Common/Downloads/Standardization_White_Paper.pdf), as viewed on November 15, 2002 (2002).