Best Practices for Integrating the Concurrent Engineering Environment into Multipartner Project Management

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Abstract: The use of the Internet, e-mail, and other technologies has been steadily filtering into the building process, creating a concurrent engineering (CE) environment, and enabling collaborative efforts in the building process. The concurrent engineering environment is established by a variety of tools, including internet accessible servers, e-mail, mobile telephones, and many other existing CE tools. Organizations involved in the construction process recognize the need for assessment of benefits resulting from CE tools, but find the evaluation of these benefits difficult and complicated. The project presented in this paper, "project management and organization in the concurrent engineering environment (ProCE)," is applicable to both researchers and practitioners. The ProCE project developed a measuring model, which may be used by future researchers in this area, attempted to measure benefits derived from using the CE environment in construction design and project management routines, and developed guidelines for best practice implementation by practitioners, based on four case studies. The project included the measurement of both the quantitative and qualitative benefit of CE environment implementation in building construction projects using tools that were readily available through application service providers. Measurement of cost and other quantifiable benefits have been extensively studied. Therefore, the majority of the discussion in the current paper will address the ProCE project's measurement of qualitative benefits.

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Introduction

The use of the Internet, e-mail, and other technologies has been steadily filtering into the building process. Together, these kinds of technologies create a concurrent engineering (CE) environment, a conceptual arena created by any or all technologies enabling collaborative efforts in the building process. A variety of tools establish the concurrent engineering environment. Internet accessible servers allow designers to store drawings in a centrally accessible location, e-mail encourages rapid written communication, and mobile telephones allow site managers to communicate with off-site personnel. An abundance of CE tools currently exist on the market.

Although there is no question that the idea of a concurrent engineering environment incites belief in the existence of incredible potential benefits, most organizations, especially those involved in the construction process, find the evaluation of information technology (IT) benefits a difficult and complicated endeavor (Churcher et al. 1996; Sethi and King 1994; Farby et al. 1992; Gillespie 1994). Churcher et al. (1996) found that most construction organizations do not perform formal evaluations of the benefit of IT investments.

In spite of the difficulty in evaluating the benefits of implementing the CE environment, the construction industry has recognized the need for meaningful benefit assessment (Carter et al. 1999). The research project presented in this paper, "project management and organization in the concurrent engineering environment" (ProCE), developed a measuring model, attempted to measure benefits derived from using the concurrent engineering environment in construction design and project management routines, and developed guidelines for best practice implementation (Luedke 2001). The guidelines for best practice were developed using a case study methodology. ProCE was a Finnish-American cooperative research project carried out from September 2000 to December 2001.

Applicability

This research is applicable to both researchers and practitioners. The measuring model developed by the ProCE project and the measured levels of benefits derived from using the concurrent engineering environment may be used by future researchers in

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this area as a baseline to compare against future studies. The review of current CE environment technologies is a useful description of the state of the art, and the methodology for measurement of qualitative benefits could find application in many areas of benefit measurement. The guidelines, based on four case studies, were developed to guide best practice implementation. This information is vital to practitioners who must choose CE tools for use on their own construction projects, and who must implement the technologies involved in a CE environment.

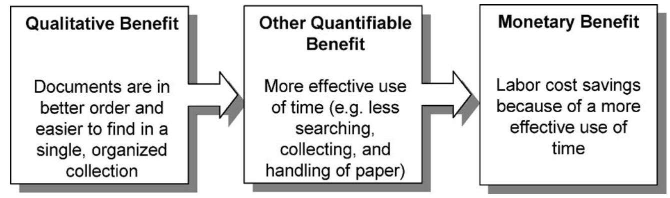

Fig. 1. Example of monetary benefits as a result of the other benefit types

State of the Art

A number of studies revealed a knowledge gap in the evaluation of IT applications (Love et al. 2005; Stewart and Mohamed 2001; Abduh and Skibniewski 2004). Most point to the need for a framework to measure the benefits provided by IT applications, and especially for the measurement of qualitative benefits, or "intangible benefits" (Stewart and Mohamed 2001). Studies have been performed to determine the utility of IT implementation (Abduh and Skibniewski 2004), to create classification methods for benefits (Love et al. 2004), to determine performance indicators (Stewart et al. 2002), to survey current practices (Love et al. 2005), and to develop performance measurements (Stewart and Mohamed 2003). However, it is apparent that "most [IT benchmarking] studies have taken a piecemeal rather than comprehensive approach by selecting individual variables as surrogates of IT sophistication…Many results are on the organizational impacts of IT, and are thus far from being comparable, systematic and valid" (Stewart and Mohamed 2001). IT implementations are most beneficial and most likely to be adopted in the construction industry if consistent and easily comparable methods of benchmarking the performance of IT applications are developed, within a logical, implementable framework for benefit measurement, but, these methods are not currently available in the construction industry (Stewart and Mohamed 2001). Stewart and Mohamed (2003) utilized the balanced scorecard (BSC) framework to evaluate IT performance, in an attempt to build on the ConstructIT (1998) framework. The ProCE project was undertaken to extend this type of effort to measure the benefits of existing CE technologies, and to develop a framework for the measurement of both quantitative and qualitative benefits of implementation in a multipartner project setting (Lakka et al. 2001).

A review of company and product literature and a market survey were completed to identify the most common components used to create the CE environment and its features. The general literature review examined over 300 companies, while the detailed market survey studied 19 European and American companies acting as application service providers (ASPs) in 2001. The detailed review included a study of product demonstrations on company Web sites and questionnaire responses from sampled service providers, giving information about commonly available features and capabilities.

The literature review and survey found that the existing CE environment in the building industry consists of three basic components: Electronically storable and transferable information, a centrally accessible location to store the electronic information, and a network for transferring the electronic information. The most common tools creating centrally accessible storage locations for the CE environment are collaborative document and project management solutions (Luedke et al. 2001). Almost all currently available multipartner collaboration solutions are used by way of ASP services, meaning that for a fee, the ASP provides tools and centrally accessible server space and requires the use of only a web browser for basic capabilities. These tools were being identified by different names, including project extranet and ASP. Common techniques, features, and capabilities of the CE-environment solutions available on the market were:

- Real time updating;
- Traditional folder tree structure to organize and manage documents;
- Notification of changes made to the hosted project information;
- Version management for managing different versions of the same file; and
- Information archiving as a part of the service.

Variable document access control was also common, meaning that document access rights could be different for each user, and the management of user access was given to a project participant, such as the project manager. Other common features were information backup as a part of the service, and document audit trails for tracking when and by whom files were uploaded to the system and when and by whom files were viewed or downloaded. Internal e-mail, or more commonly, integration of standalone e-mail software, was also included as a communication tool in many European solutions.

The features and capabilities of 2001 CE-environment solutions were simple and served well as basic, central information repositories with some integrated communication tools and links to other services, usually printing services. These solutions established a foundation for the multipartner CE environment in the building industry (Sulankivi et al. 2001).

Benefit Measuring and Evaluation Model

The ProCE project sought to investigate how existing technologies were being applied in the construction industry and to what extent project partners realized benefits. The ProCE project team developed a methodology and framework to document and measure benefit realization and applied the evaluation model to four case studies.

Methodology

The ProCE measuring methodology extended one developed by ConstructIT. The ConstructIT (1998) methodology approached benefit evaluation from the business process and single firm perspective. It identified three benefit types: efficiency ("doing things right"), effectiveness ("doing the right things"), and performance ("doing things better"). Of the three, ConstructIT identified two benefit types, efficiency and effectiveness, as measurable benefits. They identified efficiency benefits as financially measurable and effectiveness benefits as measurable, but not in monetary terms. Performance benefits were identified as not measurable, but of

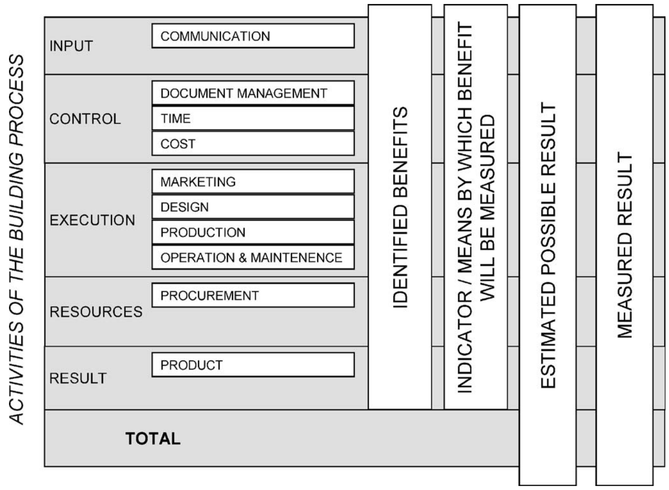

Fig. 2. Basic ProCE benefit classification matrix

significant consequence in long-term business performance. The ConstructIT methodology consisted of three phases of benefit evaluation: (1) initial identification through questionnaires; (2) benefit measurement on a series of three tables; and (3) summary of overall benefit. The ProCE evaluation methodology modified ConstructIT's approach by extending it to a multipartner, production process approach. This allowed the ProCE team to capture all benefits accruing to all organizations in the different phases of a construction project, as well as some of the costs. A project-based approach is suitable for the evaluation of the cost of CE-environment implementation because there is usually a per-project fee for use of the commercial CE environment.

The production process model used in the ProCE study consisted of four phases: (1) engineering; (2) procurement; (3) construction; and (4) facility management. This production process model integrated the engineer/procure/construct model used in the Back and Moreau (2000) IT benefit assessment methodology and the quality management system model (Sjøholt 1995) based on the building life-cycle process.

The definition of benefit types was another key concept in the ProCE measurement methodology. The ProCE team defined three types of benefits:

1. Monetary benefits: quantifiable in monetary terms;
2. Other quantifiable benefits: benefits quantifiable in other than monetary terms; and
3. Qualitative benefits: nonquantifiable benefits, described qualitatively.

The evaluation of qualitative benefits was a unique aspect of the ProCE project. Literature review showed heavy emphasis on measuring quantifiable benefits, typically monetary benefits. The ProCE team was interested in investigating qualitative benefits because, as Fig. 1 shows, these can be viewed as leading to the production of quantifiable benefits. Thus, discussion in this paper centers mostly on the measurement method for qualitative benefits.

Framework

The initial ProCE measuring framework was created based on the literature review. It was then tested and substantially developed during the first case study. The basis of the framework was a two-dimensional matrix (see Fig. 2). The resulting framework consisted of four components: (1) benefit checklist (see Table 1 for examples); (2) evaluation sheets (see Table 2 for an example); (3) summary table (Table 3); and (4) a benefit indicators list (see Table 4 for examples). An indicator is an indirect measure of a benefit (e.g., a construction schedule compressed by 3 weeks may

Table 1. Design-Phase Identified Benefits Resulting from Implementation of the CE Environment in a Building Project

Building project phase	Monetary benefits	Other quantifiable benefits	Qualitative benefits
	S11. Reduced labor and administrative costs (locating product information faster)	S21. Time savings due to fewer design errors (less rework)	S31. Better tools for collaboration improved collaboration possibilities
		S22. Improved quality of design (fewer design errors, improved constructability)	S32. Easier to share common electronic information (e.g., building layout)
		S23. Faster design change process	S33. Improved coordination of geographically dispersed resources
	S12. Cost savings due to fewer design errors (less rework)	S24. Fewer administrative tasks	S34. Increased awareness of task status
Design—Benefits		S25. Faster decision making	S35. Easier to publish updated/revised documents
Including: creating design documents and expressing meaning of designs		S26. Faster specification of building products and materials (eCommerce and other info sites)	S36. Increased accessibility to up-to-date project information S37. More complete and consistent recorded and retrieved project information
		S27. Time savings from reusing information more effectively (e.g., sharing electronic building layout)	S38. Easier to monitor design progress (e.g., for design coordinator) S39. Improved coordination of designs (e.g., management of specialty contractor designs)
Designation: S=design		S28. Fewer PCs need design software installed (can use viewer)	S40. More efficient decision-making cycle S41. Increased documentation of decision background S42. Helps to manage design change process S43. End users have more opportunities to influence design decisions because they can follow design progress

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Table 2. Evaluation Sheet for Qualitative Benefits in a Building Project

1. Activities of building project		2. Identified benefits	3. Indicator/means by which benefit will be measured (brief description, refers to more detailed information and calculations)	Expected result/possible result: 4. Likelihood of benefit occurring [%]	Expected result/possible result: 5. Qualitative rating and description of the impact of the expected benefit	Measured result: 6. Specific benefit resulting	Measured result: 7. Qualitative rating and description of the impact of the measured benefit
Input	Communication						
Control	Document management						
	Time						
	Cost						
Execution	Marketing						
	Design						
	Construction						
	Property management						
Resources	Procurement						
Result	Product/building						
						TOTAL	

Note: Scale: 4=Very significant; 1=Low significance; 3=Significant; 0=No difference; 2=Somewhat significant; and −1=Negative impact.

be an indication, or indirect measure, of benefits realized through production management efficiencies). Fig. 3 describes each of the framework's four tools and the purpose of each.

Framework Application Process

The measuring framework was developed for use in analyzing a multipartner project from a production process perspective, as compared to the perspective of a single enterprise. It can be used to measure benefits in completed projects or used as a tool for setting implementation targets in ongoing or planned projects.

The framework is used to develop the different parts of the methodology, which we call the "framework application process" (discussions follow and illustrated in Fig. 4). The measuring framework application proceeds in four stages: (1) identification of benefits; (2) preparation for measurement; (3) measurement; and (4) evaluation. These are illustrated in Fig. 4. The benefit checklist is developed to assist in task (1) identification of expected/perceived benefits. The output of this step is a list of identified benefits. These benefits are used, along with their associated indicators, to fill in the evaluation sheet tool in (2) preparation for measurement. The output from this task is a tool (evaluation sheet) that includes the indicators for the identified benefits. Indicators are used during task (2) to formulate the survey instrument to be used in data collection for (3) benefit measurement. Benefit measurement (3) takes place through interviews or questionnaires designed using the outputs from task (2). The outputs from this task are the measured benefits and the estimate of possible benefits. These are then tallied during the evaluation of benefits (4) task using the summary table (Table 4). Using this summary table, the measured benefits are then compared to the estimated benefits. This process occurs for not only qualitative benefits, which have been focused on in the current paper, but also for monetary and other quantifiable benefits. Measurement and evaluation of these benefit types are not focused on, because these methods are relatively straightforward, and have been discussed extensively in other places. Each of the four stages of the framework application is discussed in the remainder of this section.

Identification of Benefits (Stage 1)

The first stage identifies those benefits expected or acquired in the project. Expected benefits are those benefits anticipated or thought possible at the beginning of the measuring process. Acquired benefits are those benefits observed in a completed project. Benefit identification is accomplished by examining stored project information or by interviewing project staff. The framework's

Table 3. Benefit Summary Sheet

Type of benefits	Expected result/possible result (evaluated before measuring)	Measured result (resulting in a project)
Monetary benefits:		
Quantifiable in monetary terms	Total predicted monetary value	Total realized monetary value
• Direct cost benefits		
• Indirect cost benefits		
Other quantifiable benefits:		
Quantifiable but not in monetary terms	Total predicted score	Total realized score
Qualitative benefits:		
Nonquantifiable	Evaluated benefits, expressed qualitatively	Summary of realized benefits, expressed qualitatively

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Table 4. Examples of Benefits and Associated Indicators

Benefit	Indicators
Better information exchange	The application also includes communication features (not only document storage), and the users think these features offer better possibilities for information exchange
	Information can be transmitted to all project parties by the centralized system
Increased awareness of changes and project news	The application has features for this purpose
	The users think these features support and make it easier to monitor the project
More consistent information	All parties who have the right to access the information have access to the same information as it is distributed via the system
	More consistent information contents, for example, standardized forms
Personal responsibility easier to trace and monitor	System shows who has actively participated in the project and who has not
	Document time stamping and receipt notification
Fewer misunderstandings	Project participants think there were fewer misunderstandings than in "traditional projects"
Project information accessible independently of time, place, and user organization	Centralized document management location serves the entire project team
	Project data is accessible from any place and at any time
Designs in better order and easier to find	The users think this is true
Better awareness of new project information	The users think this is true
Better version management	All updated document versions were stored in the system using the identifier field
	The users find the version management better
Project information easy to retrieve for own use	The users have retrieved project information for their own use and they think it has been easy
Distribution of documents to other parties is easier	The users think this is true
Better tools for cooperation and improved cooperation possibilities	The users think this is true
More complete and consistent recorded and retrieved information	Corresponding documents stored in the system by different parties are similar in format and contents
Improved quality	Attained quality compared to average
	Fewer defects

benefit checklist can be used during both parts of this first stage, along with project staff interviews to identify both anticipated benefits and a list of potential acquired benefits. An excerpt from the benefit checklist for design-phase benefits used in this study is shown in Table 1. Identified benefits are the deliverable from this stage.

Preparation for Measurement (Stage 2)

Measurement preparation consists of recording the identified benefits (achieved or expected) onto the framework's evaluation sheets (see Table 2 for a sample of an evaluation sheet for qualitative benefits, analogous tables were used for quantitative benefits), identifying indicators and associated metrics for each benefit (see measuring framework part 4 in Fig. 3), and planning how to measure each benefit. Indicators provide quantifiable evidence that the corresponding benefit is achievable in the project under consideration, and are used in evaluating the extent to which the benefit is realized.

Indicators related to the identified qualitative benefits are pulled off of the benefit checklist developed in part 1 of the measuring framework, as shown in Fig. 3. Table 4 details the indicators used for an example collection of qualitative benefits in the ProCE project. Measurement methods are dependent on both the benefits identified and the indicators chosen. Once the indicator is identified, measurement of qualitative benefits generally proceeds as a survey of project participants. This survey will include a question designed to illicit a response for each indicator in the list. Measurement of quantitative benefits can be performed

MEASURING FRAMEWORK: *The common description of and tools for benefit measurement in any project*	
Part 1.	**Checklist**
	Purpose: Helps identify expected/perceived benefits • A list of all potential and achievable benefits gathered into one table • Three categories for different benefit types: MONETARY BENEFITS: Quantifiable in monetary terms. OTHER QUANTIFIABLE BENEFITS: Quantifiable but not in monetary terms QUALITATIVE BENEFITS: Non-quantifiable, described qualitatively • Grouped also by building project activity (where a specific benefit can be achieved)
Part 2.	**Evaluation sheets**
	Purpose: Documenting and recording calculations. • One table for each of the 3 benefit types • Columns: 1. Activities of building project (where CE environment has some influence) 2. Identified benefits 3. Indicator/means by which benefit will be measured 4. Expected result/Possible result 5. Measured result
Part 3.	**Summary table** • Measured result for each of the 3 benefit types, summarized in one table
Part 4.	**Indicators related to the checklist benefits** • Examples/proposals for indicators • An indicator is an indirect measure of a benefit

Fig. 3. Measuring framework for assessing the benefits of CE environment use in a multipartner project

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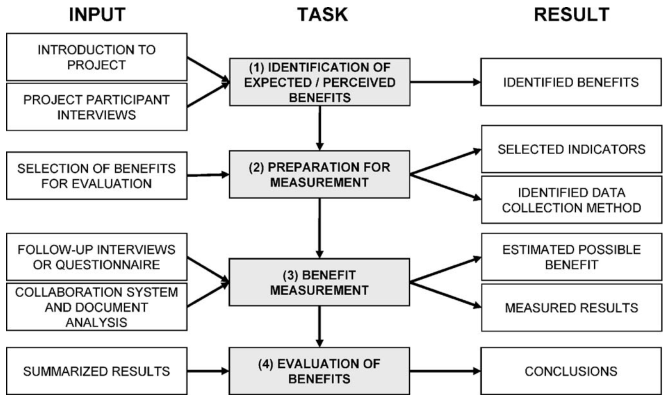

Fig. 4. Framework application process

through interviews and specific survey questions (e.g., user estimates of number of miles averted from travel, number of hours averted from travel), and/or by analyzing the centralized document archive (e.g., number of drawings produced). Stage 2 is facilitated by use of the evaluation sheet, benefit checklist, and benefit indicators. The output of this second stage includes lists of information needed for measurement, and development of measuring methods, such as the survey instrument described above.

Measurement (Stage 3)

The measuring stage evaluates the extent to which benefits were attained in a project using parts 1 and 2 of the measuring framework. Whether an ongoing or completed project, this stage can also include an estimation of maximum possible benefit. This maximum benefit estimation can be used as a goal-setting tool in the early stages of ongoing projects or, in completed projects, as a tool for gauging the success of implementation (maximized benefits indicate successful implementation). In either case, the measuring stage uses the Delphi technique for measuring either expected or acquired benefits. The Delphi evaluation technique is often used in predicting the future and is a means of conducting group discussion dealing with complex questions to which a single, correct answer does not exist. The technique gathers expert opinions about the study topic, summarizes them, presents the summary to the expert panel, and records their comments. The ProCE project used the Delphi-style method in measuring the benefit of CE-environment implementation. For qualitative benefits, users of the CE tools rated the significance of each identified benefit on a scale from −1 to 4 (−1=negative impact, 0=no difference, 1=low significance, 2=somewhat significant, 3=significant, 4=very significant). Table 2 shows the evaluation sheet used for measurement. The ProCE project did not, however, ask the expert users to come to consensus on the benefits expected/achieved nor the importance of benefits expected/achieved, as would be done in the typical Delphi method.

Evaluation (Stage 4)

Benefit evaluation focuses on comparing measured benefits to estimated maximum benefits. This stage utilizes step 3 of the measuring framework. This final stage also includes comparing the quantified value of attained benefits to costs identified. An example of this is shown in Table 3, which is an overall summary table of the quantitative and qualitative benefits accruing in a typical project. It is important to note that the study did not perform an exhaustive evaluation of costs associated with implementing the CE environment.

Case Study Descriptions

The measuring framework was applied to four case studies in Finland, Sweden, England, and the United States. Case studies were accomplished by surveys and interviews with project participants from various stages of the production process in four different countries. The tables used in the framework application process were refined as the case studies progressed. More complete discussion of the case studies can be found in Luedke (2001). Table 5 summarizes key characteristics of each case study.

Table 5. Summary of Case Study Characteristics

Case study location	Finland	Sweden	England	USA
Project schedule	Planning in 1997; construction from 1999 to late summer 2000	Design in 9/1999; construction 10/1999 to 6/2000	Design in mid-2000; construction in spring to autumn 2001	Design in early 2001; construction 6–10/2001
Project cost (millions USD)	$25.0	$7.5	$25.0	$5.2
Project type	210,000 square foot (s.f.) mixed-use office building, instruction and research, corporate office space	70,000 s.f. primary school	84,000 s.f. supermarket and adjoining development	35,000 s.f. educational training center
Contract type	Construction management	Design build	United Kingdom JCT standard traditional contract amended for partnering	Construction management/ general contractor
Construction status at time of study	Complete	Complete	In progress	In progress
Project team locations	Project partners located around the country; financier located abroad	Within 60 miles of project site	Within 200 miles of project site	Within the state of Oregon
ASP solution used	Raksanet, Tyomaatieto	Byggnet	Sarcophagus "the project"	Buzzsaw

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Finland

The project used two ASP solutions, a tool called Raksanet and a separate tool called Tyomaatieto, along with separate e-mail systems to establish the concurrent engineering environment, and also maintained a parallel, traditional paper system for distributing information. The information distribution process included the following:

- Raksanet—Used during design as a centralized design archive. Designs were saved to the system, but also delivered to the project parties on paper and to the printing service by e-mail. Building end users were given the opportunity to access the electronic document archive, allowing them to follow the progress of design.
- Tyomaatieto—Used during construction for project management. Project background information, contact information, construction phase meeting minutes, and some production planning documents, such as the construction schedule were stored on the system. Additionally, the application's electronic daily field report feature was used as well as the web camera. The web camera captured pictures of the work site, which allowed project team members to remotely follow frame construction. Meeting minutes were delivered through the system, but were also delivered on paper because subcontractors did not use the system. "Tyomaatieto" is the Finnish phrase for construction site information.

Ten project participants participated in the case study, including designers, prime contractor staff, a construction supervisor, and the real estate owner. Seventy percent of the respondents had not previously used similar ASP applications. Measured benefits for each case study are discussed below in the Case Study Results section.

Sweden

The Swedish case study used a single ASP called Byggnet to establish the concurrent engineering environment along with a separate e-mail system. All project information was delivered through the system during the design process. The system also delivered information during construction. However, not all subcontractors could access Byggnet; documents were delivered to those subcontractors on paper.

Routine paper document delivery was not used in the project. Meeting minutes, lists of drawings, and other typically A4-sized (letter-sized) documents, and 80% of designs were delivered through the system. Parties on the construction site used a personal computer with Computer Aided Design (CAD) software to print designs onto paper. Other project parties ordered paper copies from a printing service. Architectural designs were saved in both drawing (.DWG) and image (.PDF) format so that all parties were able to access and use the files as needed.

In addition to document delivery, the system was used to disseminate project notices and site images from the web camera. The request for information (RFI) feature was also used for design changes. The RFI feature was developed to formally request and provide additional information, and to document decisions.

Seven project participants participated in the case study with roles including designer, prime contractor staff, construction supervisor, and owner's representative. Sixty percent of the respondents had previous experience with Byggnet. Measured benefits for each case study are discussed below in the "Case Study Results" section.

England

The British case study included the construction of a supermarket in 17 weeks (not including site preparation or completion of the surrounding development). The project used a single ASP tool, Sarcophagus "the project," to electronically publish, disseminate, and archive a substantial amount of documents and project information during the construction phase. Documents included drawings, specifications, component schedules (e.g., finishes, reinforcement), progress reports, meeting minutes, approved changes documents, anticipated final expenditures (AFEs), construction design and management (CDM) regulations, health and safety documents, and risk assessments. In most cases, the tool replaced posting, e-mailing, or faxing drawings and other documents to the parties, and also served as a centralized project archive for documents, contact information, and site photos. The owner, design team, construction manager, prime contractor, and several subcontractors used the tool.

In addition to the use of the CE environment, the case study included another innovative information dissemination characteristic: The client established and enforced a directive for all designs to be drawn in a 1:50 (1-in. to 50 ft) scale on A3-sized (ledger sized) paper whenever allowable. This directive eliminated all A0- and A1-sized drawings except for specialty trade designs done in 1:500 and 1:1,000 scales (mainly mechanical and electrical), and significantly influenced the way the CE environment was used. Facilitated by the use of A3-sized paper, nearly all designs were distributed electronically between the main parties, and each was responsible for printing document copies to fulfill their own needs.

Seventeen project participants responded to the case study questionnaire. Roles consisted of main designers, specialty designers, prime contractor, subcontractors, and inspectors. Seventy percent of survey respondents had never used an ASP tool before, 18% had used "the project" previously, and 12% had used some comparable tool previously. Measured benefits for each case study are discussed below in the Case Study Results section.

United States

The U.S. case study investigated the application of an ASP tool called Buzzsaw during the construction phase to publish, disseminate, respond to, and archive requests for information (RFIs) and to publish, disseminate, and archive the prime contractor's drug policy. The ASP tool partially replaced faxing RFIs and the drug policy to project parties, and also served as a centralized project archive for RFIs, contact information, and the drug policy. Traditional fax continued to be used to disseminate RFI responses from some parties, including notifications, sketches corresponding to the RFI, and confirmations of information or action directives. For legal reasons, and because the two media were used to deliver corresponding information, paper copies of the RFIs continued to be archived by most of the parties. Some features of the ASP tool changed significantly during the course of the project.

A request for information is a formal document indicating additional information is required. Most often, the RFI conveys a question asked by the contractor that is answered by the designer. The RFI also documents the information exchange for later reference. The subject is often detailed information that is unclear or in error in the original design documents, such as dimensions or location of specific items, or clarification of component specifications. Requests for information are not used for actions that do not need documenting, such as requesting a copy of a drawing.

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Traditionally, RFIs are disseminated by fax between parties. It is important to note that the American case study was the only one including a formalized RFI process. Formal processes were not used in Finland, Sweden, or England because of significantly different legal systems.

The owner, design team, and construction manger/prime contractor used the Buzzsaw tool. Seven individuals responded to the case study questionnaire. Project roles consisted of owner's representative, designers, and prime contractor. Forty-three percent of case study participants had never used an ASP tool before, and 57% had used an ASP solution previously, but not Buzzsaw. Measured benefits for each case study are discussed in the Case Study Results section below.

Guidelines for Best Practice Implementation

The ProCE project identified several guidelines that are important in maximizing realized benefits from use of the CE environment in multipartner projects. These guidelines for best practice were developed by means of the case studies. The literature and market survey of company practices and the extension of the existing ConstructIT benefit measurement methodology discussed above were used as a basis for developing the case studies. The case studies were accomplished through surveys and interviews with project participants. The framework developed by the ProCE project was used to facilitate these surveys and interviews. Lessons learned from the project participants who participated in the surveys and interviews were captured and are summarized in these guidelines for best practice. When using the CE environment, the three most fundamental principles are:

1. The CE environment should be used as extensively as possible.
2. Common rules should be developed and followed.
3. Introduction of the tool should be controlled and user support given.

Some of the specific lessons learned from the ProCE research project are summarized in the following guidelines for successful implementation of the CE environment in multipartner projects:

- Establish a goal for use of the collaboration solution: By setting a clear goal at the outset of the project, the information and documents that are to be distributed, filed, or managed with the help of the system are defined. The goal naturally influences the benefits realized. In all case studies, the study team observed that project teams used the CE solutions to manage only the documents they identified initially. Thus, in Finland, Sweden, and England the collaboration solutions were used to manage many document types, while in the United States, the solution was used to manage a limited number of document types. If there is no goal for electronic document distribution via the centralized system, the dissemination process can easily break down and other parallel processes come into use.
- Avoid parallel processes that disseminate information: The selected collaboration solution should be the only method used to disseminate electronic data. The case studies indicated that potential benefits, such as savings in work time, will not be fully realized if parallel information dissemination processes are used. Parallel dissemination processes can lead to confusion about where information is published and stored, and which version is current. As seen in all the case studies, when information is disseminated both electronically and on paper, extra work results, generating resistance toward implementation of the new technology among project participants and reducing the amount of overall benefit achieved (e.g., savings in labor) via electronic distribution.
- Begin using the centralized system as comprehensively and as early as possible: The European case studies showed that early distribution and archiving via the centralized system allows the project information to be saved most effectively. Benefit potential increases with more comprehensive use of the centralized system; for example, unnecessary time delays could be eliminated during building systems' (electrical, mechanical, etc.) coordination. The European case studies also showed that the use of one centralized system is more simple and efficient than the use of two or more centralized systems.
- Achieve buy in from all parties, including subcontractors: To make the information distribution as easy and efficient as possible, delivery to all project participants should be done through one upload to the system. The Swedish and British studies showed that when all parties, including subcontractors, use the system, it is possible to achieve greater savings in work time and potential monetary benefits. Subcontractors and other parties who typically join the team later benefit by receiving information as comprehensive and correct as that used by other project participants.
- Invest in technology at levels that support a highly functioning tool: To encourage all individuals to use the system as extensively as possible, partners should invest in technology infrastructure at levels that optimize user satisfaction and economic commitment. In every case, users commented on the major inconvenience caused by downed servers or slow network connections. Server/connection down time and upload/download wait time should be minimized because users view this as a system that is not working well. Many study participants commented that if the tool did not work well, or was frustrating to use, they resisted using it.
- Introduce users to the application and its use when the project starts: Users who have no experience using the selected application or a similar system can be slow to begin using it. A 1-day introduction would generally be sufficient to introduce the application and provide some practice using it, so that users become proficient with the basic CE solution tools needed for the project.
- Include a kick-off meeting and immediately establish an IT protocol: Even if the application is already familiar to the user group, a kick-off meeting is still needed to agree on specifically how the application will be used in the project. At the kick-off meeting, the project team should agree on goals and a set of simple rules for electronic data exchange and application use. Example topics of agreement include identifying the information to be shared exclusively through the centralized system, software and file formats to be used, file naming conventions, and the responsibilities and rights of various parties.
- Follow the established procedures and rules: All the agreed-on information must be uploaded to the server and be up to date. The documents or other information that are to be maintained in the centralized databank should not be delivered outside of the system, for example by e-mail, nor by free-form communication not included in the agreement. When new information and updates are saved into the common databank, it becomes available to all project parties. For example, if one party has asked by phone for updated information, the same information does not need to be sent the following day to someone else asking for the same information. Following the procedures and

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Table 6. Summary of ProCE Case Study Results

Case	Qualitative benefit score (scale −1 to 4)	Time and other quantifiable benefits	Monetary benefits	Monetary benefit/cost ratio
Finland	2.6	• Time savings of about 200 hours (29 work days).	Project total of $17,300	2.6
	“The tool substantially helped in document and project management”	• About 1,700 fewer days of information distribution delays.		
Sweden	2.2	• Supported 4-month schedule compression. Time savings of about 50 hours (7 work days).	Project total of $8,100	1.8
	“The tool was somewhat helpful in document and project management”	• About 530 fewer days of information distribution delays.		
		• Fewer disputes related to information distribution.		
England	2.3	• Time savings of about 162 hours (20 work days).	Project total of $19,000	1.3
	“The tool was somewhat helpful in document and project management”	• About 2344 fewer days in information distribution delays.		
		• Fewer field errors.		
United States	2.3	• Forty percent time saving related to RFI process (2 days per RFI).	Project total of $27,000	22.0
	“The tool was somewhat helpful in document and project management”	• About 326 fewer days in information distribution delays.		
		• Time savings of about 365 hours (about 46 work days).		

rules ensures that different versions of the same document will not exist among the project parties.

- Designate expert users: Extensive and regular use of the tool was hindered by the absence of designated expert users. Designated individuals should have a solid, fundamental understanding of information technology and knowledge of the application used, to act as experts in their organizations. In the European studies, users commented that the existence of designated experts would have fostered additional, experimental confidence in those having limited computer experience, as they would have had a contact person to answer questions.
- Create and store information in electronic form: The basic condition for creating an extensive central distribution and project information archive is that all essential information for the project, such as designs, specifications, meeting minutes, and schedules, exists in electronic form. This is aided by new application features like offline communication documentation (i.e., tools available within the application for documenting telephone calls, conversations, etc.). However, as seen in the American study, situations still exist in which all traditional materials (e.g., RFI responses or meeting discussion summaries) are not recorded directly into electronic form.
- Ensure that the form of the electronic information is suitable for real estate: The importance of agreeing on computer software and information saving formats was discussed earlier, with a primary objective of guaranteeing that the parties involved in the design and building stages are able to open the files and use the common electronic information. Use of information by the real estate industry after the project is complete sets additional format demands that must be considered when agreeing on IT protocols. As shown in the Finnish study, file formats that are accessible to the real estate industry are more important than ever before because of a growing demand in the real estate industry to more effectively use the information collected during the design and building stages.
- Use the explanation field when saving new information on the server: It is often important for the recipients of information to quickly and unambiguously pinpoint changes made to a document, especially design documents. For this reason, an explanation field should be used when the file is uploaded, whenever possible.
- Establish rights and responsibilities: With the help of the common central databank, the various project parties have the opportunity to access more comprehensive project information. On the other hand, with the help of the new tool, individuals now have to search for the information for their own use that was produced by others, instead of expecting all pertinent documents to be sent directly to them. Awareness of the rights and responsibilities related to the new situation should be raised among project participants so each individual understands their role.
- Provide the possibility for product end users to more extensively follow the progress of the design and building stages: The project team should consider providing the project end users with the opportunity to follow the design and building progress with the help of the centralized system. Technically, this is already possible: Variable document access control within the project server provides opportunities to establish appropriate limits on individuals’ rights to access documents. In many cases, the end product will be improved if the end users are able to more widely influence project planning by reviewing designs and giving feedback. However, if different parties require varied file formats, this can mean extra work for the document publisher.

Case Study Results

Project-specific results from the four case studies are summarized in Table 6. A sample of the identified benefits from the evaluation sheet used for the U.K. case study is included as Table 7. Table 7

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Table 7. Example of Identified Qualitative Benefits in a Building Project

Building project activity	Input	Control	Execution	Resources
	Communication	Document management	Design benefits	Procurement
Identified benefits	K31. More communication facility options and better conditions to exchange information	D31. Project information available without time or location, or organizational dependency	S31. Better tools for collaboration	
		D32. Documents in better order and easier to find in a single, organized collection	S32. Easier to share common electronic information (e.g., building layout)	H31. Easier to locate information about available products and human resources (product info, subcontractor contact info)
	K32. Increased awareness of project changes and news	D33. Increased awareness of new information	S33. Improved coordination of geographically dispersed resources	
	K34. Increased individual accountability	D35. Project information can be used easily for individual purposes	S38. Easier to monitor design progress (e.g., for design coordinator)	H32. Easier to transfer information between parties (quantitative information)
		D34. Versions of a document are in better order, easier to find, and readable	S40. More efficient decision-making cycle	

shows only an excerpt from the case study evaluation sheet for illustrative purposes. It is important to note that the studied projects used the CE environment during different phases of the production process (e.g., in Finland the CE environment was used during design and construction, while in the United States, it was used during construction only). So, from the multiparty, production process perspective, the case studies analyzed the benefit of using the CE environment during the applicable phase(s) of the production process during which it was used.

In monetary terms, the time savings translated into \$8,000 to \$27,000 in savings to the project. Work hours saved ranged from 50 to 365 hours (7 to 46 work days) over the duration of the project, and there were 530 to 2,344 fewer days of information dissemination delay. Qualitatively, respondents thought the ASP solutions helped "somewhat" to "substantially" with document and project management. Qualitative responses were measured on a scale from −1 to 4, with −1 indicating respondents thought the ASP tool created problems or made a task more difficult, and 4 indicating the respondent thought the ASP solution made a task far easier. From the project perspective, benefits exceeded the direct costs incurred by application use for each case study. An extensive discussion of results is available in (Sulankivi 2004) and (Sulankivi et al. 2002).

Summary and Conclusions

The joint Finnish-American ProCE research project developed a framework and an application process to measure and evaluate the benefits of implementing the CE environment in multipartner projects. The research included the measurement of both the quantitative and qualitative benefit of CE environment implementation in various stages of building construction projects in Finland, Sweden, England, and the United States. The tools implemented in these case studies were readily available through ASPs and included features such as real time updating, folder tree document organization structure, notification of changes made to the hosted project information, file version management, and information archiving, among others. The variety of tools implemented yielded net benefits to the multipartner teams, many because of reductions in the time required to transfer information. Based on observations made during the state-of-the-art review and the four case studies, the research team developed guidelines for the best practice implementation of the concurrent engineering environment to maximize realized benefits in multipartner projects.

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