Case Studies of Web-Based Collaborative Design

Empirical Evidence for Design Process

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Abstract: Data collected from real-world projects using Web-based communications and project management systems provide quantitative evidence for characterizing the design process. Tens of thousands of records have been analyzed from six cases. The cases are all high-end office and retail building projects, with about 50 members of the design team. The data supports the distinction of multiple stages in the design process as the patterns of usage of the software changes through time. Coordination activities are more frequent in early stages, while collaboration activities are more common in late stages. In planning and design stages, use of the software is focused upon accessing static information, while in construction documentation a relatively greater number of activities include generate and process operations.

1 INTRODUCTION

Web-Based Communication Systems (WBCS) are increasingly used in the architecture, engineering and construction industry. Nonetheless, we do not know how effective they are in supporting successful collaboration and coordination (Alshawi and Ingirige 2003). It is increasingly important to understand the information and communication requirements in the AEC industry to operate successfully (Augenbroe and Eastman 1999). To obtain more confidence in such software, we need to know how they are used in daily operations by architects, engineers, consultants and building owners.

This paper describes an investigation of the communication among members of interdisciplinary teams during the planning and design phases of development and construction projects using WBCS. A typical WBCS provides multiple functions (or channels) for data storage, inspection, and communication, such as posting, accessing posted material, chat communications, email, and broadcast messages. The importance of different channels is based on different capabilities of media richness similar software differentiations are discussed by Jabi (2003). The research examines the frequency of communication among the participants and the change of information patterns over time during the design and planning process. Data has been captured automatically during the use of the WBCS in the form of transaction

logs, messages and documents. The data has been coded for form and content, documenting quantitatively when, what and which type of information is communicated from whom to whom during a building project. The analysis reveals the balance between coordination information and collaboration related information, a distinction suggested by other researchers (Jeng 2001).

The hypotheses tested are: which type of information is transferred during the project stages; how do participants use WBCS in industry; and which functions are used the most and should be provided or are not used at all.

2 DATA COLLECTION

Three major architecture firms, listed among the top AE firms in Engineering News-Record, provided their WBCS communication repositories from the planning, design and construction documentation stages of building projects for six case projects. Each case consists of up to 20,000 recorded messages or transactions. Each project team has about 50 interdisciplinary members, who perform different roles in the project, such as client, architect, contractor, engineer and consultant. All messages, transactions, and documents that have been posted, submitted or reviewed have been loaded into databases. These databases are then joined into one, by linking the corresponding field names of each project database.

2.1 Software Description

The data has been generated by using mainly two WBCS that are typical of those on the market. Both systems' common functions are file repository, calendar, team directory, and project message board. Members log on and are authenticated, and then the system records each action. Participants have an assigned access level with specified privileges such as administer, change, write, edit or view. The privileges are defined on a function, folder, or file level. However, none of the firms had limited its member's privileges, with the exception of the project client's access rights in Cases 1 and 2. The first system is a proprietary system, developed by an architecture/ engineering firm and used in-house as well as sold to outside clients. It had as an additional function: a threaded discussion board and a link list to outside information. The second system is a commercially available software package and also provided Request for Information (RFI) and Submittal functions of all digital documents. It also had a built in email function, but nobody used this email.

2.2 Case Description

Data was collected for six cases. All cases have in common that they deal with high-end office or retail spaces and that the construction costs are above 10 million US dollars. The complexity of the projects required communication among large teams of participants over a duration of several months. All teams were geographically

distributed. For this paper we limit the discussion based on data including all written or electronically exchanged documentation for each project, such as meeting notes and documents. The information from personal and back-channel and informal communication is being investigated but is beyond the scope of this paper.

Cases 1 and 2 cover the pre-planning phase until the execution phase for office buildings for telecommunication firms. The duration of observation is 50 weeks for each of these cases. Both involved in-depth considerations regarding future operations and flexibility of use. Case 3 covers the planning and design stage for a series of retail and commercial office buildings in a metropolitan setting, which has been investigated for 75 weeks. Case 4 is the design and documentation phases of a corporate headquarter for an insurance company, lasting 38 weeks. Case 5 covers 12 weeks of the design documentation phase for a mixed use high-rise building that includes retail floors and office spaces. Case 6 documents 50 weeks of communication from the design development until construction administration phases of an urban retail building.

One limitation of this research is that not all emails that have been exchanged were available, due to the fact that all members used their corporate Exchange Server, which was not integrated with the WBCS functions. Since verbal communication and face-to-face could not been captured over a long period, written meeting agendas and meeting notes were provided by the firms. In further research that is not yet complete, we will account for the verbal and undocumented exchanges by conducting interviews with key participants.

3 CONTENT ANALYSIS CODING SCHEMAS

We have used content analysis techniques to assign distinct categories to data and complement inferences derived from quantitative observations. The data from the cases has been coded in accordance with the four variables of communication according to Shannon and Weaver (1998): sender, channel, content, and receiver.

The participants have been coded to provide anonymity and to distinguish normalized roles. These roles include six hierarchical levels of personnel per firm corresponding to executive, director, lead engineer or project architect, specialist or architect, and administrative staff. The mapping between person and title to the role has been based primarily through personal discussion with the firms or teams.

Although the software does much of the coding of the transactions automatically, inspection by the researchers is still necessary. The software records the sender, the intended receiver, the channel and the time. The message itself reveals three dimensions of content: data behaviour, coordination/ collaboration tasks and design activity. Data behaviour distinguishes actions of generating, accessing/ reading and then processing information (Baya and Leifer 1996). The discussion of collaboration and coordination is essential to discuss CSCW, because different activities require different tools and means (Kvan 1997, 2000). The coordination dimension is derived from Coordination Theory (Malone and Crowston 1994). Huang (1999) previously

applied this theory to design studies. Messages are coded as either supporting coordination to enable team members to share decisions and manage the workflow or supporting collaboration to produce decisions and solve problems. Coding for design activity uses the categories analysis, synthesis and evaluation to produce a representation of how designers work and think (Purcell et al. 1996). Because the design activity coding is in progress, a report on the results will be presented in a future paper.

The categories are assigned by using data mining/ content analysis software that is trained to find keywords in context; manual coding supplements the automated coding for complex or extended documents and messages. According to best practice for research, samples of computer and manual coding are independently coded by human coders, to check for reliability of coding (Neuendorf 2002).

Our method provides a very rich source for analysis to uncover possible correlations and relations. We are able to characterize usage of the WBCS by participant or role, across phases of a project, and according to multiple models of message purpose. In this report we only describe the quantitative results herein, but further coding of the data could provide evidence in favour or in refutation of various design methodology theories.

Descriptive statistics have been used to produce a first level of analysis. This article presents simple correlations to time and person that have been used to drive inferences about how the WBCS has been used. Future work will present more sophisticated correlation studies.

4 ANALYSIS RESULTS: CHANGES IN COMMUNICATION PATTERNS

The analysis of the data draws a quantitative network of actors in the planning process of building projects. The results at this stage target the work tasks and the information behaviour of the project participants, based upon electronically documented communications and transactions.

4.1 Activity by Location

The use of communication through WBCS is more than twice as frequent among firms as within firms. Some participants were located at central offices, while others occupied branch office facilities. For this study, central offices are considered those that have 10 project members or are part of the corporate headquarters of a participating firm. Similarly, remotely located team members contribute over twice as many transactions than members located in headquarter offices. Cases 1 and 2 involved multiple offices of international firms, consisting of architects, engineers, planners and consultants. Each project member averaged 141 transactions over a 50 week period. Members of remotely located offices that had a small number of team members at the office or were in non-metropolitan settings used the system more

frequent, with up to 310 transactions. This result is not surprising as one might expect that project members who are geographically far from the primary location for the project would rely more on telecommunications, include the WBCS.

4.2 Coordination versus Collaboration

The dimension of coordination versus collaboration provides additional insights. Figures 1 and 2 compare percentage of coordination activities below the line and percentage of collaboration activities above the line for all cases. Since each project was studied for a different duration, the total time for each case has been subdivided into 25 equal "time units". The figures also show a trend line and extremes. The two figures differentiate between cases that were oriented toward the planning and design stage versus cases focused upon construction documentation.

From the graphs, several conclusions can be drawn. Group coordination messages are the most frequently observed category at the project inception and within each project stage itself. They decline in frequency with the progression of the project while the collaboration messages increase (Figure 1 and 2). Progression from coordination to collaboration parallels a change in software functions from "pure messages" to "task assignments" and finally to "documentation and drawings." The appearance of flurries of message of one category type within a phase characterized by another category type needs still more study. Perhaps distinctions of sub-phases or confirmation of a cyclic pattern of design activities will emerge from more detailed analysis.

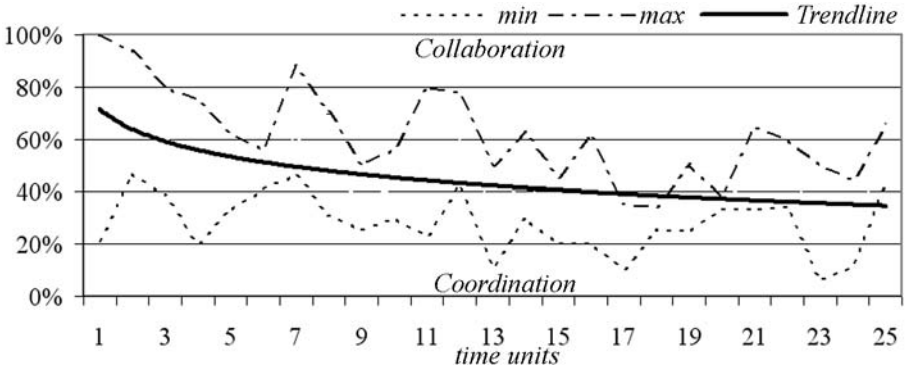

Figure 1 Planning and Design Stage Ratio between Coordination and Collaboration over Project Duration

The figures illustrate a qualitative difference between the two categories of case. In cases that focused upon planning and design, illustrated in Figure 1, the proportion of coordination activities decreased dramatically over time. It starts out at about 70% and then declines to below 40% on average. In the cases focused upon construction documentation, shown in Figure 2, the mix between coordination and

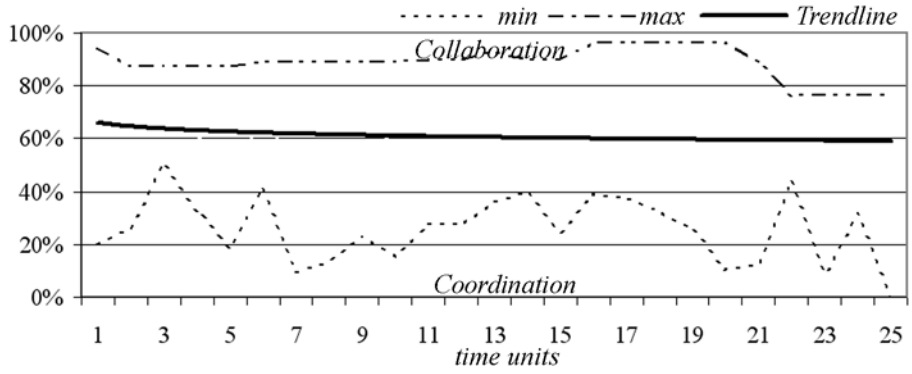

Figure 2 Construction Documentation Stage Ratios between Coordination and Collaboration over Project Duration

collaboration stayed more constant for the duration, declining only about 10%. This difference in shape of these curves suggests that the distinction between early and late design is an accurate model of design processes. Perhaps, in the cases with more coordination, the constructor was already involved. The involvement of new participants probably requires a great effort of coordination prior to collaboration.

4.3 Information Behaviour

The difference between stages is also apparent from analysis of the kind of activity. Figures 3 and 4 show the proportion of activities for each normalized time unit as grouped into classifications of “access”, “generate”, and “process.” Across all cases, 80% of the transactions are only accessing or reading information, while not contributing new information to the information pool:

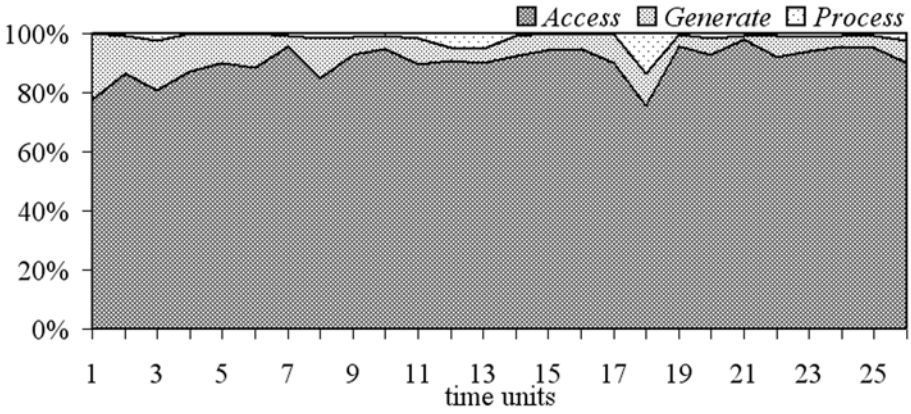

Figure 3 Information Behaviour over Project Duration for Planning and Design Development Stage

Figure 3 shows that 90% of the activities in the early stages are accessing information for reading and assimilation. In construction documentation, only 50% of activities were for accessing information, as visible in Figure 4. Generating new information and processing data account for the remainder of transactions or messages.

With progression of the project, the information type changes from pure messages, review of background information, and negotiations to more output and production oriented information. The study shows that the main production of new issues or documents, such as drawings and detailed descriptions of the building, is accomplished at the later phases of the projects.

An actual tracking of the change in information type over the project life cycle requires longer observation of each case over the whole life cycle. Not all cases have gone through all stages of design, construction and operation. Further study such as the content analysis may allow a more complete picture of which information is used at each stage.

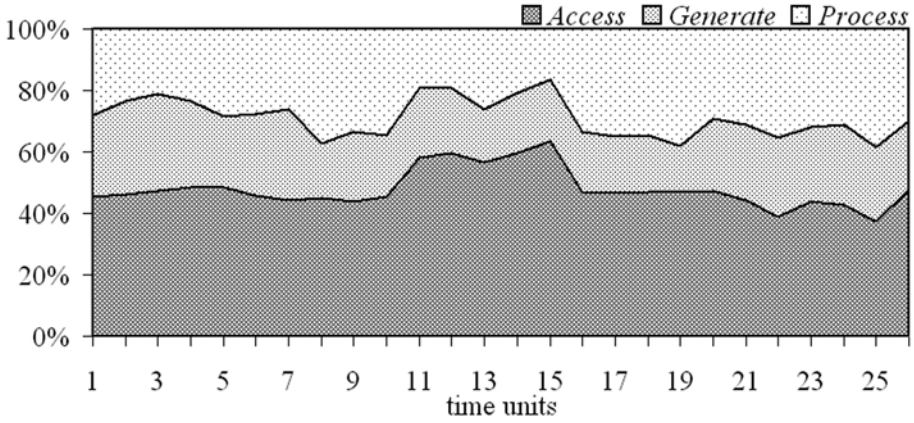

Figure 4 Information Behaviour over Project Duration for Construction Documentation

4.4 Messages According to Organizational Hierarchy

At the beginning of all efforts is the question “who is going to do the work?” One main question this study tries to answer is which who performs which work tasks in the planning and design process. Dividing all messages and transactions based on content analysis into collaboration and coordination tasks, the following picture can be drawn in relation to the hierarchy of authors of each message or transaction.

Coordination is done by participants more in the middle range of hierarchy, such as lead engineers and specialist (Table 1). Collaboration or exchange of information takes place at the specialist and administrative staff level. This can be interpreted as the specialists produce the results, but are coordinated by their leaders and directors.

Although the software supports non-hierarchical interaction among team members, most information is routed along company hierarchy lines rather than directly to the ultimate receiver. In this case the software design does not match the organizational form. Nevertheless it has to be considered that a high ranked employee in the firm usually is assigned to more than one project at a time and might therefore not contribute as many messages to a single project.

Table 1 Task versus Hierarchy of Employee

Tasks	Exec.	Direct	Lead	Speci.	Intern	Staff	
Collaboration	11.9%	15.0%	16.0%	23.8%	0.0%	33.3%	100%
Coordination	6.3%	13.4%	25.7%	35.9%	4.0%	14.6%	100%

Table 2 further indicates that most of the accessing or reading of electronically available information is done on a specialist level. The messages or information is then worked on and presented outside the WBCS to the team leader. The team leader then submits the newly generated information into the system. Based on the log information frequently team members send “new” or “process” information to their staff assistants for submission or distribution into the WBCS. This is similar to the traditional way of doing business by delegating tasks to subordinates who can monitor the flow of information into and out of an executive office, although anybody could directly send information to the intended final receiver.

Table 2 Information Behaviour versus Hierarchy of Employee

Inform.	Exec.	Direct	Lead	Speci.	Intern	Staff	
Access	4.1%	15.8%	20.1%	45.7%	2.5%	11.9%	100%
Generate	7.1%	12.6%	27.3%	23.6%	5.1%	24.3%	100%
Process	6.5%	22.0%	36.2%	15.1%	0.4%	19.8%	100%

5 IMPLICATIONS AND CONCLUSIONS

By inspecting the transactions of WBCS, the traffic flow of information in the design process can be observed. This research draws conclusions about the work tasks and communication behaviour of architects and engineers using digital communication systems by employing large amounts of empirical data that can be subjected to quantitative analysis. This data allows us to assess the adequacy of WBCS with respect to theory. As a by-product, the research has produced evidence for validity of design methods theory. The results will be useful in formulating recommendations for improvements of existing communication software tools, streamlining the exchange process in AEC, and achieving higher user acceptance.

Information flow in design process: The research has produced evidence regarding who participates at various stages of the design process, how they use information, and how they share information throughout the team. The data confirm that a WBCS is most useful in distributed organizations and may be most critical to branch office operations. Coordination efforts are particularly important in the early stages of a project, while collaboration activities dominate at later stages. From the cases studied, one can conclude that the planning and design stage exhibits a high degree of coordination at the beginning and proportionally more collaboration later, while construction documentation exhibits a more consistent split throughout the process. The planning and design stage is overwhelmingly dominated by access operations to the information rather than generate or process operations. Construction documentation is more heavily characterized by generate and process activities. These observations lend credence to design method theory that distinguishes the design process into distinct stages.

The different categories of employee require different functions and support. While high-level employees make relatively small use of the software, the bulk of activities recorded are performed by specialists, lead professionals, and staff. Although executives undertake access, generate and process functions, indicating a range of expertise, there may be opportunities to streamline processes by using non-hierarchical access instead of traditional divisions of authority by status.

Improvements to software design: Both software packages effectively support document repository, calendaring and general project notification. The versioning and the mail function have not been used at all and thus may not be perceived as valuable. Due to storage space and associated cost for the architect, prior versions of documents were always deleted from the WBCS and recovery was difficult. Three cases successfully used the threaded discussion board to solve generic issues. Compared to individual messages that covered the similar topic repeatingly, topics addressed using the threaded discussion did not need to be "renegotiated." A threaded discussion is useful.

Miscellaneous conclusions: The four cases which had buy-in from the senior executive in the architecture firms used WBCS the most, versus the cases when the client was the driving factor for the use of the WBCS. This relates to a required change of mindset in the architecture industry to utilize digital means to increase and smooth the flow of information.

New research method: The use of transaction logs from Web-based software is a new form of design research that produces highly reliable and valid evidence in the design methods.

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