CONTENT ANALYSIS OF WEB-BASED COLLABORATIVE DESIGN
Empirical Evidence of design process

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Web-Based Communication Systems (WBCS) are project specific web sites that provide dedicated web hosted "collaboration and information spaces" for the AEC industry to support design, engineering and construction teams. These systems have an underlying software structure that is shared for many independent building projects. A typical system provides controlled access to the project data from any physical location through the Internet. WBCS can have various features, such as email, message board, document repository, calendar functions, to-do-lists, and project administrative features.

The software itself is not new; it has already been applied in architecture and even more in engineering. Current studies indicate that there are over 260 WBCS available on the market (Orr 2004). However, many architects are hesitant to use the new technology and are not convinced of its potential. The concern firms share is that a WBCS may waste time or fail to enable a successful project (Laiserin 2002). The question is: do WBCS tools contribute effectively to building projects?

Current research has investigated several limited aspects of Web-based communication. Previous studies have generally dealt with data from an experimental setting or are single case studies. The objective of this study is to measure the use of WBCS within AEC. This study employs a new approach in AEC research by using data produced as a byproduct of the commercial use of design support software.

MOTIVATION

The architecture industry may be undergoing a major shift in the way it conducts business; it appears to be shifting towards a Design-Build operation, according to Cramer (2003). Firms and teams are working more closely together. As outlined by Cohen (2000), Orr (2004) and Laiserin (2003), integration of technology is required to streamline businesses and support the AEC organizations .

A few companies have already been successful using advanced integrated information exchange to improve their bottom line (Johnson and Laepple 2003). However, the industry still lacks a system that supports the information flow over the entire building project cycle (Alshawi and Ingirige 2003). Some market analysts suggest that WBCS will reach a $25 billion market in a few years (Gartner Group 2001). To reach this level, improvements of existing systems are necessary, but to do so the current use in practice must be known. This research investigates the actual use of these Web-Based Communication Systems to help software developers produce better products and better meet the demands of this expanding market.

PRIOR WORK

Other researchers have investigated the use of Web-based tools applied to architectural design. Engeli and Kurman (1996), Kolarevic (2000), Latch and Zimring (2000) have conducted research on Web-based tools to explore educational settings or small short-term projects. The data in their studies is produced under experimental conditions, such as classroom environments and the conclusions may not be generalizable to industrial applications. Secondly, they are focused on prototype Web tools rather than common applications. In another effort, Verheijn studied the theoretical functions of commercial WBCS, which he considered as "*Teaming, Coordination, Collaboration and Communication*" (Verheij and Augenbroe 2001, p20). In contrast to these earlier works, this study has investigated the actual use of WBCS in commercial architectural and engineering practice.

There have been a number of studies in the field of design methods that target how practitioners work. Recent studies have rarely employed quantitative analysis. A few studies have used an experimental environment or single case studies. Cross has conducted some of the most rigorous research in the field of design activity in AEC industry using protocol analysis (Cross, Christiaans, and Dorst 1996). They observed designers at work and coded their activities by time and category to allow generalization. Another example of protocol analysis studied the stages of analysis, synthesis and evaluation in design process (Purcell et al. 1996). Another research effort has performed interaction analysis on videotapes of a series of design charettes to develop characterizations of how architects use Internet-based telecommunications (Al-Qawasmi and Clayton 2000).

These studies were focused on small numbers of participants and within an educational environment. Our research examines large project teams of actual building projects involving hundreds of designers and thousands of transactions to drive conclusions about design methods.

The categorization of content in these studies is challenging as Verheijn indicated. Malone proposed a more theoretical model, *Coordination Theory*. This theory characterizes coordination as "*managing dependencies among activities*" (Malone and Crowston 1994, p90). However, the application of Coordination Theory to the AEC industry has been limited to primarily theoretical investigations and "empirical studies are clearly needed to illuminate the situation" of the utilization of Internet based project nets (Huang and Tovar 2000). This study combines Verheijn and Malone's definition of coordination and distinguishes the work tasks into coordination and collaboration. Collaboration for this study is seen as: *The interaction of at least two people to achieve a common goal.*

The second content category is information behavior (of the user). What is the participant using the data and system for? Baya and Leifer laid out simple and successful the three steps that can be done with data: Generate, Access and Process (1996).

METHODOLOGY

This study applies a multi-method approach to generate a clear image of the use of WBCS. It employs the following steps: review of previous research, and analysis of data of actual building projects. Qualitative interviews are planned but have yet to be conducted. Briefly, the study is organized in the following steps:

- Review published literature.
- Identify partners from industry.
- Collect transaction records from firms.
- Code records by transaction form and content analysis.
- Statistically evaluate frequency of coded values and find correlations.
- Synthesize analytical results to produce conclusions.

The crux of the research method is to analyze the data that is automatically collected by WBCS during real-world projects. Data from six projects led by three different AE firms has been collected, resulting in a dataset of over 50,000 messages. More detail on the sample is provided in the section on Description of Cases.

RESEARCH QUESTION

The existence of this dataset has led us to postulate a large number of research question that can reveal how WBCS are used and what they can achieve in architecture and engineering projects. The basic research question (Do WBCS tools contribute effectively to building projects?) can be decomposed into a number of quantifiable sub-questions, some of them discussed herein are:

Is Information Flow Driven by Senders or Receivers? Traditionally, the sender directly addresses information to the receiver via letter or email, but a WBCS can be used as broadcasting tool. With the introduction of a common repository it seems that the receiver determines which information to retrieve (Monge et al. 1998). A study of transactions may determine how much information is sent directly for quick attention and how much information is posted for the convenience of the receiver.

Is the Use of Functions Dependent on Type of Information to Be Conveyed? Each role in the design and planning process must accomplish different types of work. In theory, different software functions (calendar, document repository, message board, email) may be more appropriate for each kind of work. For example, while a project manager has to coordinate and communicate, an architect may be more likely to use collaboration. The transaction logs can be searched for a correlation between user role and channel of communication.

Does Information Type Change Over Time? Different stages of a design project may involve different types of information. By coding the transactions recorded by the WBCS by information type, it is possible to study the frequency of transactions in relation to project stage.

Does Location of Office or Participant Influence the Use? One would expect that if a user is geographically outside a metropolitan area, away from the main offices or other central locations, where participants physically meet would use it more frequent.

Does Software Hierarchy Equal the Organizational Hierarchy? WBCS have been developed as non-hierarchical tools that allow anyone on a team to easily communicate with anyone else. Have architecture teams adopted this non-hierarchical, flat organizational model or do they work in a more traditional hierarchy? By studying the sequence of messages and transactions as they are relayed through the system it may be possible to reach conclusions about the form of the organization.

CONTENT ANALYSIS

Several of these questions depend upon an analysis not only of the transaction type and time, but also the content of the information communicated. Content analysis has been conducted to investigate these issues. The unit of observation is a transaction record in the WBCS. Each time a participant sends a message, confirms a transaction, or uploads or edits a file, the WBCS documents the access to the data and marks entity (log entry). The entity has associated variables such as content type, time, and roles (sender and receiver).

The goal of every quantitative analysis is to produce counts of categories and measurements of the amounts of variables. The variables chosen are of manifest content of the data; they can be read directly from the message, since elements are physically present and countable (Gray and Densten 1998). The study differentiates between two types of variables: form and content.

FORM VARIABLES

The three form variables are source, channel and receiver. The *Source* reflects the sender of the information. It is measured as a nominal variable [nominal]. The *Channel* stands for the channel of exchange, which is the function that has been used to relay the message [nominal]. The number of nominal categories is determined by the system analyzed. The *Receiver* of a message is the participant or role to whom it is addressed [nominal]. The form variables rely on hard, objective data inside the actual message that describes the form of the message transmitted.

CONTENT VARIABLE

The fourth variable message is a content variable. The messages are investigated for their content category [nominal], timestamp [interval], task of message [nominal] and information behavior [nominal].

The content variable classifies each message into a priori categories that are developed according to existing literature. Because there are many theories of design that name and distinguish activities within the overall process, the research employs many categorization variables. Each transaction is assigned to a design strategy, which follows from Asimow (1962). These categories are analysis that describes the problem, synthesis that generates a candidate solution, evaluation that assesses the viability of a candidate solution, and administrative issues. Nevertheless, before the detailed coding scheme is finalized, professionals were asked to comment on the coding, preventing gaffes. The goal is to generate a set of complete and unambiguous categories.

EVIDENCE FROM CASE STUDIES

A perfectly representative sample is impossible, since access to this data is limited. In many firms, like software companies, the owners and the architects are hesitant to provide unfiltered confidential information of this kind. They are afraid of losing competitive advantage, providing proprietary data, and or legal disputes. These are obstacles obtaining a random sample and having access to the full target population. Inevitably a study such as this one will employ convenience sampling. Three firms have agreed to share information about past building planning/ design projects.

Since the availability of data determines the building type to be analyzed, a strict limitation to one type of building project is not feasible. In personal discussion with the researcher, high ranking administrators of the companies selected projects, from which the sample has been drawn.

DESCRIPTION OF CASES

Three major architecture firms, listed among the top AE firms, 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 a variety of 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 one joint databases.

All six cases have in common that they deal with high-end office or retail spaces and that the construction costs are each above 10 million United States dollars. The complexity of the projects required communication among large teams of participants over several months. The data includes all written or electronically exchanged documentation for each project.

Cases 1 and 2 cover the pre-planning until project execution phases for office buildings for telecommunication firms. The duration of observation is 50 weeks for each of these cases. Both cases 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, and 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 is that not all emails that have been exchanged were available, due to the fact that team members used a corporate mail server that was not integrated with the WBCS functions. Since verbal communication and face-to-face communications 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 conduct a series of interviews to account for the verbal and undocumented exchanges.

SYSTEM DESCRIPTION

In the six cases, the three AE firms used two WBCS that are typical of those on the market. Both systems provide common functions of 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 like administer, change, write, or view. 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.

System Type A is a proprietary system, developed by an architecture/ engineering firm and used inhouse as well as sold to outside clients. It has additional functions of a threaded discussion board and a link list to outside information.

System Type B is a commercially available software package. It provided additional functions for managing Requests for Information (RFI) and Submittals, with version control of all digital documents. It also has a built-in email function, which was not used.

Some candidate projects were eliminated from the study because the software provider would not consent to objective testing without prior guarantees.

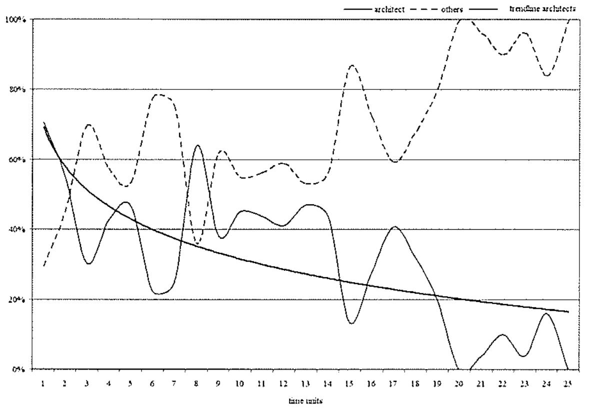

Figure 1. Contributions by firm over time: Case study 2

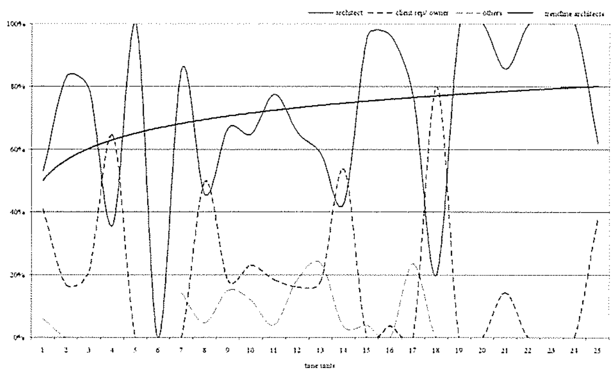

Figure 2. Contributions by firm over time: Case study 6

DATA ANALYSIS

ROLE OF PARTICIPANTS

The majority of document and transactions have been submitted by architecture firms and their employees. The percentage of transactions changes from week to week. Below are two sets of typical curves. Cases 1 and 2 describe projects in the early design stages, such as strategic planning and schematic design (Figure 1). In these cases, the amount of architecture contributions is steadily increasing. The communication by non-architects is mainly from owner representatives. Cases 4 and 6 are projects during the construction documentation and administration phase (Figure 2). Both charts indicate a decreasing amount of contributions from the architect, while the number of contributions by particularly engineers is increasing.

All cases, but Case 1, clearly indicate the ping-pong cycle of communications and interactions among the firms. Typically, one group, such as the architects, proposes and discusses a solution in-house and then passes it on to the next group, such as engineers or consultants. This pattern explains the ups and downs along the time line: there is strong activity in one group while low activity in the other group.

HIERARCHY WITHIN FIRMS IN RELATION TO SYSTEMS USE

At the beginning of all efforts is the question "who is going to do the work?" To answer this question in more detail beyond the firm level, one main question this study tries to answer is; which work tasks are performed by whom? 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 senders of each messages.

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 1. Task 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%

Table 2. Information Behavior versus Hierarchy of Employee

Coordination takes place primarily in the mid-range of the hierarchy, such as among lead engineers and specialists (Table 1) (Laepple, Clayton, and Johnson in print). Collaboration or exchange of information takes place at the specialist and administrative staff level. One might say that 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. The software design does not match the organizational form. Nevertheless, it has to be considered that a highly 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 2 further indicates that most of the accessing or reading of electronically available information is done on a specialist level (Laepple, Clayton, and Johnson in print). The messages or information is then worked on and presented outside the WBCS to the team leader. The team leader then feeds the newly generated information into the system. Based on the log information, team members frequently send "new" or "process" information to their staff assistants for submission and distribution. 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. The teams in the cases have not made use of the capability to send information directly to the intended final receiver.

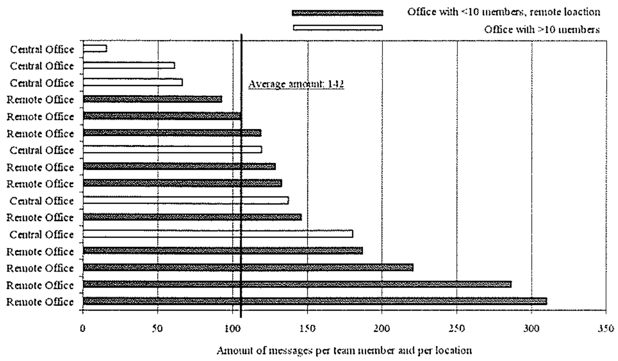

Figure 3. Average amount of activities per user and time unit, based on their location

ACTIVITIES IN RELATION TO LOCATION

The above two sections answer, on a quantitative level, who is doing the work. This section considers the impact of whether a participant is in a central location or in a remote or client site location. Some participants were located at central offices, while others occupied branch office facilities. For this study, central offices are considered those that have over 10 project members or are part of the corporate headquarters of a firm.

The use of communication through WBCS is more than twice as frequent among firms as within firms (Figure 3). Similarly, remotely located team members contribute over twice as many transactions than members located in headquarter offices. Cases 1 and 2 (which are reflected in the figure) involved multiple offices of international firms, consisting of architects, engineers, planners and consultants. Each participant averaged 141 transactions over observed 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 frequently, with up to 310 transactions. This result is not surprising as members who are geographically far from the primary location for the project would rely more on telecommunications, include the WBCS.

THE INTENDED RECEIVERS OF INFORMATION

A significant difference among messages is whether they have an intended receiver or not. If they have an indented receiver, are they addressed, routed or sent directly to the intended role or group? The software provides functions that have informative character to the entire project team, such as announcements, link lists, and are posted to the WBCS site without an intended receiver. A second group of WBCS functions includes documents, emails, and notifications that have or should be directly send to a receiver.

In the cases studied, the software appears to have influenced the routing of the information. System B had a default setting, which demanded a concrete receiver named. In System A, a receiver was not required to be specified to submit information. Based on the quantitative data, Case 5 and 6, which employed System B, used mainly defined receivers (70 percent of the messages), partially due to the fact that it involved many RFIs. Case 3 and 4, which employed System A, used the entire system as a document repository, but with well defined indexes. The system was used as a "pull system;" it is up to the unspecified receiver to "find" the information needed. Case 1 and 2, which employed System A, used a system of categories in which each document was classified. The users knew the category for which they were responsible and could browse the repository by the latest entries. "None addressed" messages and announcements were always linked from the opening webpage.

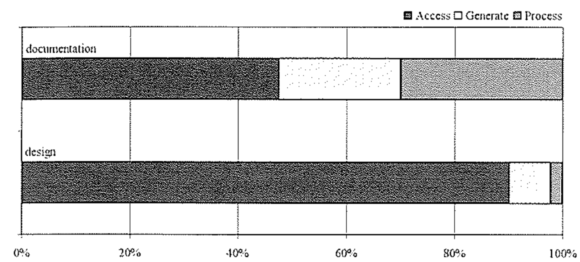

Figure 4. Information behavior during design development stage verse construction documentation

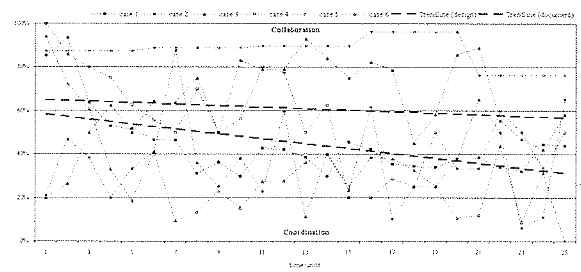

Figure 5. Changes in ratio between coordination and collaboration over time

SHIFTS OF INFORMATION BEHAVIOR

The difference between stages is also apparent from analysis of the kind of activity. (Figure 4) shows the proportion of activities grouped into classifications of "access," "generate," and "process." Across all cases, the majority of all transactions are only accessing information and do not contribute new information to the information pool. Ninety percent of the activities in the early design stages are accessing information for reading and assimilation. In construction documentation, only 50 percent of activities were for accessing information, as illustrated in. Generating new information and processing information accounts for the remainder of transactions.

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. Also, the involvement of the owner is lower towards the later stages of the project.

An actual tracking of the change in information type over the project life cycle requires longer observation of each case. Not all cases have yet gone through all stages of design, construction, and operation. Further study is collecting additional information that may allow a more complete picture of which information is used over the project life.

VARIATIONS IN WORK TASKS

As the industry globalizes, collaboration becomes a core requirement. The practical reality is that collaboration requires a higher order of involvement and a different approach to sharing and creating information; "collaborative environments have to be created" (Schrage 1990). To enable coding of the data, the study uses the following definitions for each:

The dimension of coordination versus collaboration provides additional insights. (Figure 5) compare average 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. Progression from coordination to collaboration parallels a change in software functions from "pure messages" to "task assignments" and further to "documentation." The appearance of flurries of message of one category type within a phase characterized by another category type needs still more study. (Laepple, Clayton, and Johnson in print)

The figures document a qualitative difference between the two types of cases. In planning and design cases, illustrated in (Figure 5), the proportion of coordination activities decreased dramatically over time. It begins at 70 percent and then declines to below 40 percent on average. In the cases focused on construction documentation, shown in the mix between coordination and collaboration, stayed more constant for the duration of the project, declining only slightly.

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.

SUMMARY OF OUTCOME

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 operations or process operations. Construction documentation is more heavily characterized by generate activities 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, such as executives and directors, make relatively small use of the software, the bulk of activities recorded by the WBCS are performed by the specialists, lead professionals, and staff. However, executives and directors undertake access, generate, and process functions, indicating a wide range of expertise and responsibility.

NEW RESEARCH APPROACH

Logging the use of Web-based communication for research purposes has not previously been conducted at this scale. This research uses existing data from practice at a large scale to support content analysis of design activity. It is uncommon to conduct quantitative research in communication in architecture using samples from practice, but it has proven to be promising. Independent of the actual outcome of the analyses, future research can adapt this method and conduct more detailed studies in the area of AEC. 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 field of design methods.

ASSESS ADEQUACY OF WBCS WITH RESPECT TO THEORY AND SUBJECTIVE ASSESSMENT

This research produces comparisons between Web-based Communication Systems and theory relating to this technology. This provides reasons to adjust the software or the business organization. The research documents the subjective assessment of users towards the WBCS. This provides evidence for the AEC industry and or the software industry regarding how the communication systems are designed and implemented in this field. The research may lead to new theory of design process or modification of existing theories.

COLLABORATIVE DESIGN PRACTICE AND IMPACT ON THE PRACTICE OF ARCHITECTURE

The entire study is based on records of actual communication among participants in the AEC industry. The research produces an image of how collaboration is conducted currently in practice, in particular using digital means of communication. The research indicates a frequent mismatch of the WBCS with the organizational structure. While the WBCS are designed to facilitate flat organizational structures, the design teams in these observations use traditional hierarchical structures. Either the organizational structure or the software should be adjusted.

LIMITATIONS OF STUDY

The conclusions are based on a quantitative content analysis. Hence, back-channel communication has not been addressed. The face-to-face and back-channel communication is part of continuing study with the same industry partners. The future study may show what information is not transferred by the system and why.

OVERALL SIGNIFICANCE

The building sector is entering a new era. Developments in ICT have an impact on the entire building life cycle as described by Jabi (2000), and Johnson and Kolarevic (1999). More knowledge of IT use in the AEC is needed; this study contributes to this body of knowledge.

The research explains vital characteristics of the AEC industry. This may increase the productivity and the quality of architecture projects, in a future where IT becomes more vital than ever before. The documented communication patterns could support efforts to model flows of communication and collaboration in the future.

Currently, the majority of architecture firms could technically utilize WBCS, since the systems are readily available on the market, but many firms are skeptical. The research leads to several suggestions regarding how to improve WBCS software and its use in practice. The analyses indicate that a clear routing of information is often not provided either by the user or by the software. It may be appropriate to change the software or adjust the organization workflow by encouraging clearer routing by the senders. Too much time may be wasted if receivers have to look out constantly for messages that could be of importance to them.

If patterns of communication in the AEC industry are better known, more advanced software can be developed to support AEC work structures. From this research and further studies, the AEC industry can gain a better understanding of requirements of software, reduce barriers of acceptance, and reduce potential for data loss during communication. Better software will increase the speed of project processing and lead to financial gains or savings for the industry and owners.

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