EXPLORING PROJECT COLLABORATION SYSTEMS IN THE BUILDING INDUSTRY

A Dissertation

by

EBERHARD SEBASTIAN LAEPPLE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2005

Major Subject: Architecture

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Approved by:

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ABSTRACT

Exploring Project Collaboration Systems in the

Building Industry. (August 2005)

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The use of Web-Based-Collaboration-Systems (WBCS) continues to grow as part of information technology development in the Architecture-Engineering-Construction (AEC) industry. WBCS provide different media channels to support collaboration across geographical distributed teams. However, many companies are still hesitant to integrate WBCS.

This research provides an understanding of how WBCS are used in practice. Most distinctively, it obtained practice data from several major US architecture firms and examined about 30,000 transactions produced during actual design and planning projects as practicing architects, engineers and consultants used WBCS. The study investigated what information was used and exchanged among participants during the different design stages. This was related to the different media channels of WBCS.

The raw project data has been coded and transformed into secondary data through computer-supported content analysis. Based upon categories from previous literature, such as communication, coordination and design theories, the data has been analyzed for sender, receiver, channel and content of information transmitted. The content

has been characterized into work tasks, information handling behavior and design activities.

Additional interviews with industry professionals produced information that had not been documented through WBCS and that corroborated the analytical findings. The combination of theory, quantitative, and qualitative analysis has been synthesized into a portrait of WBCS usage that was validated through triangulation.

The analysis of digital records of design communication from practice through content analysis is a new research methodology in AEC. The evidence supporting design methods theory shows the changes in tasks and information handling in regards to the project phases. It indicates that the most frequent loops of design activity are Evaluation-Analysis-Synthesis and Evaluation-Synthesis-Evaluation. It documents the actual usage of WBCS based on descriptive statistics and Markov models. WBCS was used primarily as a document repository and calendaring tool. The remote team members used it more frequently than centrally located participants. The study shows the limitations of WBCS: none of the verbal communication was captured. More significant, the entire email exchange took place outside the WBCS. WBCS was used very extensively, if the implementation of the system supported the organizational structure and vice versa.

DEDICATION

To my lovely wife Jessica Beatriz

and my parents Marianne and Ulrich Laepple

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Many family members, friends and colleagues have contributed to my research. My parents, Marianne and Ulrich Laepple encouraged and supported me during all my years, mentally, emotionally and financially.

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The CRS Center for Leadership and Management in the Design and Construction Industry, its faculty members, students and staff provided an ideal working environment for my studies. Together with the CRS Fellowship, it provided more than physical space and reliable financial support. It was a breeding ground of many insightful discussions, bridging over several disciplines. Thank you to all the industry partners and friends who made the study possible by providing this great set of data. Thank you to the William Wayne Caudill Fellowship, the Texas A&M Association of Former Students and the Philadelphia IFMA chapter for their great financial support.

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NOMENCLATURE

AEC	Architecture, Engineering and Construction
BIM	Building Information Model
CAAD	Computer Aided Architectural Design
CMC	Computer Mediated Collaboration
CPM	Critical Path Method
CSCW	Computer Supported Cooperative Work
FTP	File Transfer Protocol
IAI	International Alliance of Interoperability
ICT	Information and Communication Technology
RFI	Request for Information
VDT	Virtual Design Team
WBCS	Web-based Collaboration System

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1 INTRODUCTION

The slow adoption of innovative telecommunication systems has been the subject of observation by leading researchers. The construction industry has established a tradition of collaborative working between architects, engineers and consultants. Until a few years ago, the design process of new buildings began with physical meetings between representatives of the principal design disciplines. Increasingly information and communications technologies (ICT) have been utilized to support these meetings. The application of ICTs had some success but also had some difficulties. One challenge is dealing with the various software tools each trade is using and their data. While the design and engineering teams became more geographical distributed, occasionally spanning continents, the industry lacked effective collaboration tools that are necessary to collapse the time and distance constraints. Anumba et al. (2002, 89) stated that “in particular, there are very few tools available to support distributed asynchronous collaboration.”

The use of Web-Based Collaboration Systems (WBCS) continues to grow, and their adoption within the Architecture-Engineering-Construction (AEC) industry increases. They provide many opportunities and they are praised as effective tools in the AEC industry. Nevertheless, many firms are still hesitant to apply these technologies and integrate them into their work process.

This dissertation follows the style of *Journal of Planning Education and Research.*

The goal of this research is to increase our understanding of how these tools are used in practice and to learn how they can be used better. This research investigates the communication of data during the planning and design phase of building projects using WBCS. The study is based upon previous literature that covers coordination, communication and design methods theories. Most distinctively, this research has collected evidence by examining tens of thousands of transactions produced during actual design and planning projects as practicing architects, engineers and consultants used WBCS.

The narrowly focused research question is: what information is used or exchanged among participants in the building design and planning process at what time using which media channels of WBCS? The study used data obtained from several major US architecture firms that employ WBCS during the stages of feasibility, design and construction documentation phase of building projects that have been recently finished or passed the design stages. The raw data has been coded and transformed into secondary data through Content analysis. Based upon categories from collaboration theories and design methodologies, the data has been analyzed for sender, receiver, channel and content of information transmitted. The channel refers to the means of communication and corresponds to the function of the software used to communicate, e.g. document repository, message board or calendar entry. The content relates to characterization of the intended task of a message, such as teaming effort, communicating information, coordinating tasks, or collaboration efforts.

An additional interview phase with industry professionals has produced information that was not documented through the WBCS. This complements the analytical results. The combination of theory, quantitative, and qualitative analysis has been synthesized into a portrait of WBCS usage that is validated through triangulation. The synthesis explains the communication patterns observed with respect to established theories. The findings have been documented in graphical and verbal format. The contributions include:

1. It is a new research methodology in AEC, an analysis of digital records of design communications from actual practice through content analysis.
2. Evidence supporting design methods theory, analysis indicates that the most frequent design activity sequences observed are Evaluation - Analysis - Synthesis and Evaluation - Synthesis - Evaluation. These findings can reject neither Asimow's traditional design theory nor Schön's reflective approach.
3. Assessment of adequacy of WBCS for industry use, WBCS is primarily used as document repository and calendaring tool. Remote team members more frequently utilize it than central located participants. It can only be very successful, if the implementation of the system supports the organizational structure and vice versa.
4. The limitations of the WBCS are that they do not capture all project communication. None of the verbal communication is stored, which means team members communicate with other members or broadcast through other means too. More significant is that email exchange is completely beyond the WBCS; although the system provides the feature, users do not use it at all.

The outcome of the study has significant impact on the software design for WBCS in architecture, engineering and construction. WBCS are project specific Web-sites that provide dedicated Web hosted *collaboration and information spaces* for the AEC industry, supporting design, engineering and construction teams. These systems use the underlying software structure for many independent building projects. The system provides controlled access to the project data from any physical location through the Internet. WBCS provide various features, such as email, message board, document repository, calendar functions, to-do-list, and project administrative features.

In the mid 1990’s early online-based AEC applications in architecture were developed. Programs, such as Microstation’s Team Mate and Autodesk’s Workcenter provided document and workflow management, but failed to break through. In 1996 Web-based solutions, such as Blueline-Online, Constructware started to appear on the market. These later systems were develop by non-traditional AEC software manufacturers and transformed into mature products such as Cephren and Buzzsaw. Soon after, traditional AEC software manufacturers bought mature systems and marketed them to all AEC firms as standard for the future. However, regardless of the marketing, too many AEC firms are still hesitant to use them. The question is why. The answer lies in an investigation of the use of current systems.

1.1 PROBLEM STATEMENT

Current studies indicate that there are over 260 online project collaboration systems (WBCS) available on the market (Orr 2004). Nevertheless, many architecture firms are hesitant using the new online collaboration systems and are not convinced of their potential. The concern firms share is that WBCS do not enable them to achieve successful projects or may even waste more time (Laiserin 2002). However, is this concern justified? An objective evaluation requires knowledge of how the currently employed systems are actually used in practice. At this point neither the WBCS usage is known nor for which tasks and to which extent it is used. The current reports are more anecdotal or are mostly small-scale laboratory experiments, but are not based on industry data. Do these information systems match the way architects and engineers conduct their daily business? The answer to this question would provide an image of the actual use and applicability of this developing information technology to the AEC industry. Alternatively, what can we learn from ten thousands of communication messages or transaction about the collaborative architectural practice?

1.2 RESEARCH QUESTIONS

The investigation into whether WBCS tools contribute effectively to building projects is a large-scale question. This investigation is needed to reveal how systems are used and what they achieve. To solving this large puzzle, it needs to be broken down into manageable pieces. The puzzle can be separated into a number of quantifiable sub-questions.

> **What is the extent of the overall WBCS usage?** Depending on the project stage, does the frequency of WBCS use change over time? This is tested by a comparison of overall frequency of communication messages and transaction per time increment to the different stages of the entire building process.

Is the flow of information driven by the sender or the receiver? Traditionally the sender directly addresses information to the receiver via letter or email. However, the WBCS leaves it unanswered where information is directed to. It can target selected receivers, but it can also be broadcasting tool. With the introduction of a common data repositories 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.

Are software functions used depending on the type of information? Each participant or role in the design and planning process needs to accomplish different types of work, which might require different software functions (calendar, document repository, message board, email). For example, a project manager has to coordinate and communicate, whereas architects are likely to use primarily collaboration. Are the functions used depending on the type of information transmitted?

Does the information type change over time? The type of communication and its content might change with the progression of the project. Is this different per project stage?

Is the software structure appropriate for the organizational structure or work process? WBCS are developed as non-hierarchical tools. Everybody can write and read as they please. Architecture and engineering teams might still work along hierarchy lines. What is the effect of this apparent mismatch?

What channels are supported? The research targets the utilization of WBCS; this includes tests of which information has been communicated outside the WBCS, such as telephone, personal email or face-to-face. A significant use of *outside* channels implies that the software does not have sufficient resources to accommodate the user's requirement or it is under utilized. This links directly to the whether WBCS has the capability to accommodate all collaboration means for a successful project?

1.3 RESEARCH JUSTIFICATION

At the beginning of each research is the question, why conduct a particular research. The goal of the study is contributing to the body of knowledge, exploring and testing facts or theories. This dissertation contributes to the body of knowledge by providing an answer to the above problem statement and questions.

Any potential research needs to show four components to be worthwhile to purse. It needs an original idea, an indication of the significance of the study, an indication of generalizability of possible results, and a convincing argument that the study will produce evidence of facts.

1.3.1 ORIGINALITY

The software itself is not new; it has already been applied in architecture and even more in engineering. The objective of this study is to measure the use of WBCS within AEC. Previous research investigated several limited aspects of Web-based collaboration. The studies generally dealt with data from an experimental setting and employed single case studies. This research is a new approach in AEC of documentation and research using data produced as a byproduct of the use of design support software.

Kolarevic et al. (2000) and Latch and Zimring (2000) conducted research on Web-based tools exploring educational settings or small short-term projects. Kolarevic et al. set up a virtual design studio, in which students at universities on three continents worked together for one week in a Virtual Design Studio (VDS). It was set up that always one team could work based on a shared project that was stored in one database and accessed through the Internet. It was an experiment to test how future collaboration systems could work. Latch and Zimring describe a Web-based online graduate-level architectural studio and gave special attention to patterns of online behavior and the perceptions of those who used the environment. It was hypothesized that open participation can be fostered by a sense of community, however, the study failed to promote open interaction and did not appear to sustain a strong sense of community.

The data in their studies was produced under experimental conditions such as classroom environments; therefore, the results depend on the experimental setup. Secondly, they focused on prototype Web tools rather than common applications. Verheij and Augenbroe (2001) studied the theoretical capabilities of commercial WBCS. However, none of the above studies have investigated the actual usage. I have investigated the actual use of WBCS in practice.

There have been a number of studies in the field of design methods, targeting how practitioners work. Recent studies have rarely employed quantitative analysis. A few studies used an experimental environment or single case studies. Cross, Gero and

Purcell have conducted the most significant research in the field of design activity in AEC industry using protocol analysis (Cross, Christiaans, and Dorst 1996). Purcell et al.'s (1996) contribution to the Delft Design Workshop is a well-recognized study. They investigated design activity through protocol and content analysis. Gero and McNeill (1998) began to develop a methodology to study the process of actual designing, using protocol studies of designers engaged in design. All their studies focused on smaller numbers of participants or were within an experimental or educational environment.

The categorization of content in this study is challenging. The two basic models, which will be explained later in more detail, are Verheij and Augenbroe's (2001) proposed categorization for WBCS based upon the tasks AEC teams have to accomplish during a project. The collaboration task model described the general collaborative functions required for virtual teams to operate. The second model is Thomas Malone's more theoretical model of coordination theory (Malone and Crowston 1994). It focused on the activities and dependencies of collaboration processes and tried to develop a coordination based process model. Both have been applied to AEC industry. The latter has been applied by Huang and Tovar (2000, 1), who pointed out that: "empirical studies of their usage are clearly needed to illuminate the situation" of utilization of Internet based project nets.

1.3.2 INDICATION OF SIGNIFICANCE

Market research has shown that the current AEC applications worldwide have reached over $1.1 billion in 2003 in revenue and have a potential to increase (Wu 2004). The architecture industry is foreseeing a major shift in the way it conducts business; it is shifting towards a Design-Build operation (Cramer 2003). Firms and teams are working more closely together. Integration of technology is required to streamline the business and to support the AEC organizations for this change as outlined by Cohen (2000), Orr (2004) and Laiserin (2003). A few companies have already been successful using advanced integrated information exchange to reduce costs and improve profitability (Johnson and Laepple 2003). Nevertheless, the industry still lacks a system that supports the information flow over the entire building project cycle (Alshawi and Ingirige 2003). Previous software development for online collaboration systems targeted the interface and attempted to accommodate the users' needs, but I consider it not always very successful. It focused on the interface between the project and the client's organization. Only recently, the development shifted towards the flow of information and its activities. This new focus "targets the activities that actually add value" (Alshawi and Ingirige 2003, 362). Hence it becomes more important to understand the content of the information and how users utilize the online collaboration systems. Improvements of existing systems are necessary, but to be added to do so, the current use in practice must be known. To ground improvement of such software, this study investigated the actual use of these WBCS that are part of a large global market.

1.3.3 GENERALIZABILITY

By using data from real projects obtained from several firms, this research is relatively generalizable.

1.3.4 PRODUCTION OF EVIDENCE

The study produced evidence of information handling behavior, work task distributions and information flow using WBCS, which have not been investigated in that depth prior. The strength of the evidence is exceptional as it is based on practitioner's data and not from experimental or controlled environments. A detailed explanation of the research results can be found in the section 5.

1.4 CONTRIBUTION

This research explores the use of WBCS in the building industry. The research contribution is three fold. The first part is applying computer-supported content analysis to communication and transaction data. The method is not new, but has not been applied at this scale previously to industry data in architectural research.

The second part is an image on how the collaboration system is used in the day-to-day operation. The system appears to work well for calendaring and general project information. It supports large amounts of coordination efforts to achieve a common building project. In terms of collaboration, it designers tend to decide to early in the process on a solution, which needs to be revised later in the process. This generates additional work or efforts. The major use of the online systems is as data repository of the most up to date version. Unfortunately, past project data is taken off-line very soon and does not allow new project members to review or gain access to older information, potentially to understand the original design intent. However, the system does not capture any email or verbal communication. Hence, it never shows the entire project communication. Some of the reasons are that the software is not perfectly appropriate for the task or the organizational structures are not matched with the system.

The third part is beyond the actual exploration of the online system. The content analysis of the data provides a good picture of design activity and how it relates to practice. Through a Markov process model it documents the most frequent sequences of design activity. The first sequence is *evaluation* - *analysis* - *synthesis,* which is part of the classical study of design theory. The second sequence is closer to the ideas of the reflective practitioner: *evaluation* - *synthesis* - *evaluation*. This indicates that designers often do not really analyze a situation; they rather use their tacit knowledge or apply standard rules and propose a solution immediately. It is similar to the engineering testing approach.

1.5 OUTLINE

This outline describes what the reader can expect in each section of the dissertation. This first section provides the basic concepts and significance of the study. Section 2 describes previous literature and establishes the starting and reference anchors for the dissertation. Previous research is the inspiration and motivation for this research. The lack of particular knowledge provides justification for this dissertation. It starts with a summary of current technology development in the AEC industry and the use of computer-supported-collaborative-work (CSCW) in the architecture business. This then turns into a discussion of the state of the art CSCW in general and its potentials, as argued in existing literature. The following section describes the theories, which drive the content analysis and its characteristic components: coordination theory, information handling behavior, and design theory.

Section 3 describes the research methodology of triangulation among theory, records produced by the software and practitioner interviews regarding the use of online collaboration tools. This extensive section outlines computer-aided content analysis applied to industry data at a large scale, a new research method for the field of architecture and design.

Section 4 describes the actual data. It includes a description of each of the cases, which are the individual projects observed. The second section is a description of the different WBCS software packages used during the projects. It covers a description of the functionality of each collaboration software package used in any of the cases. It provides descriptive statistics of the data collected from the WBCS files.

Section 5 provides interpretation of the data. It explains higher-level statistical analysis to uncover patterns in the data related sequences. It addresses work tasks, information handling behavior and design activity as content variables. The form variables and the results of their interpretation succeed as hierarchical issues in firms, occupational characteristics of participants, intended receivers of messages and influence of the location factor on the use of online collaboration tools. This rich source led to information about data that has not been transferred through the online system. The section describes discussions with practitioners of the study, before all research findings of this study are compared and synthesized in at the end of this section.

Section 6 summarizes the findings and points out the conclusions. The dissertation closes with the significance of the study and the outlook into future possible studies.

1.6 GLOSSARY

The glossary lists the main definitions used in the study; a detailed description and explanation of terminology follow in the literature review and methodology sections.

Activity: is the classification of categories of design activity. Such is related to the architectural design process. It differentiates the categories of *analysis, evaluation* and *synthesis*.

Classification – Category – Sub-category: coding of data is carried out on different levels of detail. The highest level of detail is the classification, which is information handling behavior, work task and design activity. Each classification can be divided into categories, which themselves have sub-categories.

Function or Channel: functions are the different features in the information space that the software or system provides. Such features can be email, message board, calendar, threaded discussion, document repository, or others. In communication studies, they are also called *channels*.

Message: a message is every transaction that takes place through WBCS. Every feed of information into the system is a message. A message or transaction is also every access of information, such as reading a document, or editing an existing document or posting an appointment to the calendar. The system records log data every time information is accessed, added, edited or deleted in the system.

Role: is a person in the building process, who obtains a certain position and responsibility such as project architect or project manager.

Receiver: is a person or role that accesses or receives the message, information or data. This can also be a group of people. If a person accesses data and then comments on it, he is first the receiver and then the sender.

Sender: is a person or role, who sends information or messages and submits or contributes data to the project.

Task: this classification defines the different work tasks that roles have to accomplish. Such tasks can be categorized into *collaboration* efforts or *coordination* efforts, which each have sub-categories themselves.

Type: relates to the types of information handling behavior of a message, another classification. The categories of type are related to the processing of information. They are distinguished into *generate*, *access* and *process*.

WBCS: a Web-based collaboration system is an online project collaboration software. It serves as a communication and document repository during the design and construction process of building and planning projects. The strength is its 24 hours accessibility from any location that provides Internet access. The level of access can be defined for every user individually or on a group level. Any team member such as, architect, engineer, owner or consultant can be granted access to the most updated information, assuming that the system is operated properly. A detailed description of a typical WBCS follows in section 2.1.1.

2 LITERATURE REVIEW

In this study, it is important to elaborate on established theories of related fields to provide a baseline. The salient related fields are information technology developments and their integration in the AEC industry, architectural design theories, collaboration and coordination methods, and information handling behavior.

This research consists of four cornerstones of thoughts. The integration of information technology in the AEC is a very slow process; however, the discussion shows that it has potential for major impacts on overall AEC efficiency. Collaborative software is one of the information and communication technologies (ICT) addressed in the literature review. The systems support in particular geographically dispersed team members, who work together on shared projects. The capacity and the mechanics of collaboration and coordination discuss methods and techniques how groups of people work together to accomplish common goals. They provide guidance of what technology needs to afford to be supporting the collaborative mission of AEC firms. Successful designers and planners do not work alone, they need to collaborate and to coordinate to achieve their common goals. They need coordination of their efforts, tasks, and activities. Information and communication technology can bridge these gaps and is one of way to support collaboration and coordination. The study of ICT in AEC needs to consider how architects and engineers achieve their design work. The design theory discusses how the design thinking takes place.

2.1 INTRODUCTION

In recent years, the economy demands architects, engineers, owners and clients to become more flexible and to work beyond the commonly established boundaries of geography and team configurations. The increase of globalization and specialization in the design and building industry have produced a stipulation for collaboration among partners in even remote locations. Team members have become more geographically distributed, making it essential to rely on effective information and communication technology. This technology is already available, but it might not be used to the extent possible. It is inconsistent in interfaces, capabilities and data exchange format. Even assuming that technology would provide the most efficient means for exchanging information, currently the tasks challenging each participant in established practice remain sequential. Hence, the architect or engineers at the downstream end of the process have only little influence at earlier stages of the design process, where decision changes would not result in such costly changes.

Anumba et al. (2002) provided examples that the architectural design is usually substantially complete before the start of structural design. This implies that the design is at an advanced stage before, the structural, mechanical and electrical engineers begin their design. In many cases, design is finished before a contractor is given the contract and its documents, which separates the design from the construction process. This is of particular concern, since many researchers and practitioners stated that the real building knowledge lies with the contractor or the manufacturer (Johnson and Laepple 2003). The results of this disconnect are well known in academia and industry. Anumba and Ruikar

(2002) listed in their paper a number of government documents that clearly recognized the need for improvement of collaboration in the construction industry (Griesser 2004; Gallaher et al. 2004) .

Some advocates argued that the ideal solution of any design and construction project would be that all participants could work on a building or planning project and have always the latest design or information in a database accessible 24 hors per day, 7 days a week. It should not make a difference, if the team works synchronously or asynchronously. This is in particular important for an increasingly complex industry, such as AEC industry. WBCS are considered powerful tools as Kolarevic et al. (2000, 74) stated:

> *“They could collaborate on a shared object and no information would thus be lost in transfer of project data. But to be successful, this emerging type of collaboration often requires new design and communication methods."*

2.1.1 WEB-BASED PROJECT COLLABORATION SOFTWARE

Web-based project collaboration systems are project specific Websites that are dedicated Web hosted “collaboration and information spaces” for the AEC industry that support design and construction teams. This Websites allow an exactly defined group of project participants to communicate and to access project related information and data. The entire information is stored in a single database, hosted on a server somewhere on at a secure physical site.

At the beginning or at a certain point during a design project, an IT manager or project manager at a firm sets up a Website, which is usually based on a corporate template or a template provided by the WBCS application service provider. The opening Website contains usually a brief project description at its *homepage* and a menu of functions. Access to the site is via an Extranet and controlled via a username and a password that is given to users as deemed by the project manager of a specific project. The level of access can be defined by an administrator on a project, folder or file basis, similar to any MS Windows based file sharing system.

The concept of WBCS is that every participant has access to project data 24 hours a day, 7 days a week from any location on the globe, which has some kind of secure Internet connection. The functions can be manifold. The most common function is the basic data or file storage repository. It is an upgraded and more secure version of a file-transfer-protocol (FTP) site. Some WBCS applications also allow storing all versions and revisions of any file. However, the latest version is the default view.

Other common functions are a scheduling and calendaring function that shows meetings and deadlines or project keystones. Other functions are discussion boards, announcements, project directories and even more AEC specific functionality, such as Request-for-Information (RFI) features or submittal tracking. Theoretically, there are no limits to the functionality. The limitation is more likely the abilities of the users to operate the software functions.

The main distinction between any of the WBCS is, whether it is in-house software, custom designed or a major off-the-shelf software solution.

2.1.2 RECENT DEVELOPMENTS IN ARCHITECTURE INDUSTRY

The real estate and construction industry is one of the largest industries in the world, maybe even the largest with $4 trillion in construction volume, which was equivalent to 10% of the global economy in 2001 (CEMCRE 2001). In the United States of America about $800 billion of construction accounts for one fifth of the worldwide construction volume and 8% of the US GDP, single home construction generates half of that. The other half is commercial buildings, infrastructure projects, plants, and factories.

This large industry is increasing in its complexity. During any project, the status constantly changes, from a concept through feasibility phase, design, execution, and finally project completion phase. Information is continuously added, edited or replaced. The complexity of planning and building is reflected by the large number of specialists, who contribute to the decision-making process through their contributions. With clients becoming more demanding and the scope of the projects growing, the number of specialists increases (Alshawi and Ingirige 2003). Since each of them has its own expertise that is required to put a solid building project together, project members have always been encouraged to work together. In these cases two or more members work on their own domains towards a shared problem. However, in most cases the design still moves forward only in sequential steps (Kvan 2000).

Given the same resources, the decision making process remains efficient in a complex system, only if results can be accomplished faster through better information flow. This creates pressure on the team members to produce more quick and communicate more efficient. However, there is a problem: professionals such as architects and engineers need to change the way they have done business for decades to cope with these changes and developments. The organizations need to become more dynamic to perform knowledge-based services. The future organizations should be spider webs that can spun from small, globally dispersed, ad hoc teams to independent organizational entities (Jarvenpaa and Ives 1994). Architects need to adjust or restructure the way their contracts, methods, procedure, or tools worked for past generations. However, they are resistant to change, maybe due to the high standard of care required from the profession (Laiserin 2002). For example, contractors and developers are engaged in inherently high-risk activities as their core business. They do not like to change towards non-core business functions. Large portions of the AEC industry argued to have good reason to be more resistant to change than many other industries or services, such as financial services. A second reason for the slow move towards the exchange of information through digital communication tools or further integration of technology is identified as the "old-fashioned management of exchanged information" (Zhiliang et al. 2004, 629). The industry has not reached the point of standard information models and information exchange. These steps are repeated and the changes have to be reentered repeatedly. A truly inefficient system that does not contribute to the industry developments and is far behind in innovation compared to other non-agricultural businesses in the US.

2.1.3 TECHNOLOGY INTEGRATION IN AEC

Although perhaps more slowly than in other industries, the ubiquity of the Internet and all its associated technologies have started to change the building business. The emerging collaboration and project management software provide closer and more efficient communication to a very fragmented industry (Teicholz 2004). Projects are far more complicated today than ever before and involve larger capital investments. They encompass several disciplines, widely dispersed project participants, tighter schedules, and stringent quality standards (Alshawi and Ingirige 2003). These factors, in combination with ICT are already influencing the project management practices. They have produced WBCS and other tools that are highly praised. Nevertheless, these tools have not convinced the majority of potential users. Yet, taking advantage of newly developed project management tools and the latest technology may be the key to retaining a competitive position and operate a successful business. Since these promising tools have just been develop, investigation of their current use is needed to keep improving them, providing better tools and organizations for the future of AEC industry.

Online collaboration and project management services allow the industry and its partners, even the owners and clients, a completely new way of communication and information exchange. The services are designed to assist document changes and to facilitate modifications. This can reduce the number of errors or omissions due to the lack and loss of communication, which can result in a more efficient design and building delivery process.

Prototypes of such collaboration tools in architecture have been developed at universities and tested in an educational setting. Beginning in the early 1990’s instructors and students at several universities around the world worked together in a virtual design studios (McCullough, Mitchell, and Purcell 1990; Mitchell and McCullough 1991). At that time they used off-the-shelf technology like e-mail, CU-See-Me Internet video, and QuickTime animations. In combination with international conference calls and the exchange of CAD drawings via Internet, they collaborated as one international design team (Gross et al. 1998; Vasquez de Velasco 2002; Vasquez de Velasco and Jimenez 1997). Other studies and experiments followed, many of which have been categorized as *Virtual Design Studios* (Engeli and Kurmann 1996; Johnson 2000; Kolarevic et al. 1998; Russell 2001). These were attempts to span distance in a cost effective way and to bridge time zones by enabling asynchronous collaboration. Good collaboration processes in architecture took place with participants, who were not close in proximity and without expensive travel.

Technical collaboration affects more and more people, bringing them together to bear on a specific task (Coleman and Kutner 1997). The development of bridging the distance has now reached a technological point, where firms outsource entire project planning phases, such as construction documentation overseas to save labor costs (Teicholz 2004).

Going beyond collaboration, other technologies have been developed that use one information model, to encompass the entire building information set. All project participants are then able to access any information about the building during the entire building lifecycle. The GSA (Government Service Administration) has passed a ruling that all their projects planned for FY 2006 need to be submitted as Building Information Model (BIM) beginning mid July 2005 (Silver 2005). The development of BIM is discussed in more detail in section 2.2.4.

2.2 DESIGN THEORY

Understanding the work processes of architects and engineers is important to understand how WBCS are being used. Design theory research distinguishes three strains, each focusing on different methods of design thinking. The first strain is the normative approach, as referred to by many design methodologists, which solves the problem through a very systematic approach. The focus is on the design tasks and their sequence as a process. Authors who address the question of design as *Problem Solving* are Asimow (1962), Jones (1984; 1970), and Cross, Naughton, and Walker (1981) and Simon (1969). Related rational models of design include and Peña and Parshall's (2001) *Problem Seeking* and Christopher Alexander's *Pattern Language* (Alexander, Ishikawa, and Silverstein 1977).

The second strain is the empirical approach, to the design process that suggests that the designer in practice rarely follows the normative theorists. The prescriptive theoretical accounts often do not consider the real world and environmental rules practitioners face, such as time and economic constraints (Stempfle and Badtke-Schaub 2002, 474). It is questionable, whether both strains should be compared, since the rational design theory provides a simplification and framework of the process, while the empirical approach provides descriptions.

The third strain focuses even more on the environmental restrictions; it aims at the practitioner as the basis of research and argues that design theory cannot capture the practice at all. The strain refers to *design-as-an art* theory. The reflective approach focuses on the environment in which the designer operates. Donald Schön's (1983) observations have great influence on this theory. He argued that design develops through an ongoing cycle of interaction between the designer and the external representation of the designer's ideas and expressions. He termed the cycle "reflection in action." The succeeding paragraphs provide a critical overview of the first and the third strain, and of some of the hybrid theories.

2.2.1 PROBLEM SOLVING AS A RATIONAL PROCESS

Problem solving theories received substantial attention in the 1960's, perhaps as the computer raise philosophical questions regarding artificial intelligence. Theories of this period described design as a rational process following a systematic sequence of gathering, analyzing, testing, and selecting alternatives.

Herbert Simon (1960) proposed the most well known three-stage model of intelligence in problem analysis, design as idea generation, and choice as evaluation and selection process. Al-Qawasmi (1999) summarized Simon's approach as *intelligence stage* being the phase where the problem is recognized and information is gathered to spell out the problem definitions. During the *design stage*, alternative problem solutions are developed, which are selected or even implemented during the *choice phase*.

Other researchers followed Simons's three-stage process model in several variations, among them Morris Asimow (1962). He explained that an engineering project can be structured into a chain of vertical processes or stages. The vertical morphology begins with the needs analysis, followed by the feasibility study, the detailed design, and so on (see Table 1). He stated that within each vertical phase there is a horizontal structure, organizing the process within the stage. This same horizontal structure repeats itself over time. It is the typical sequence he called the *design process*. It is a distinctive process for solving the problems of engineering in Asimow's opinion. His model describes the design process of gathering, handling and creative organizing of ideas and concepts relevant to a problem situation. It is a decision making process that aims to communicate, optimize, test, and evaluate alternatives and solutions. He distinguished between two main phases (see Figure 1). The first phase of primary design consists of feasibility study, preliminary design and detailed design. The second phase is the actual production and operation phase. Most of the cases observed in this study are located in the primary design phase.

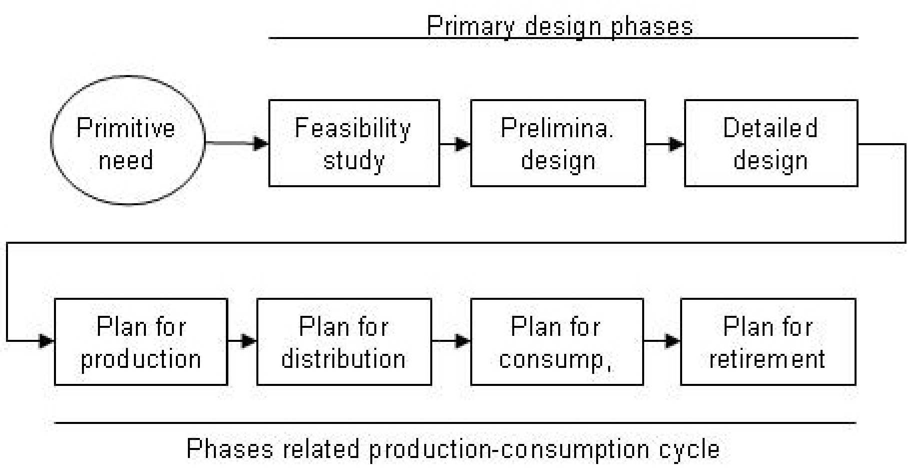

Figure 1. Phases of a complete project: design and production. Adopted from Asimow's phases of design (Asimow 1962, 12).

The separation of the steps in engineering design as outlined by Asimow (1962) is still widely recognized today. Gielingh's (1988) current model (see Figure 2) is a projection of Asimow's model onto today's building industry. This is an indication that this theory is applicable even to current design efforts, regardless of whether engineering design has its own peculiar way of problem solving. The process remains largely the same, regardless of who described the major steps of problem solving despite the different terminology. Gielingh's model focused more on a practical application than Asimow's model. Gielingh's model described the "transition" points between each stage of the process, which is similar to the stages an architect encounters during a project and for which he bills the client. At the later part of this research, the cases analyze differences in the communications between these studies.

Edward Hodnett (1955) spoke of *diagnosis*, *attack*, *scientific method*, and *art*. Another writer, Eugene von Fange (1959) in "Professional Creativity," listed the steps as: *define*, *search*, *evaluate*, and *select*. Sometimes the last element is called revision. Reviewing the above phrases and selection of words, revision can be added as fourth stage to the elements above to enable solving more complicated problems. This is more appropriate today, since several iterations are usually required for the resolution of increasingly complex problems.

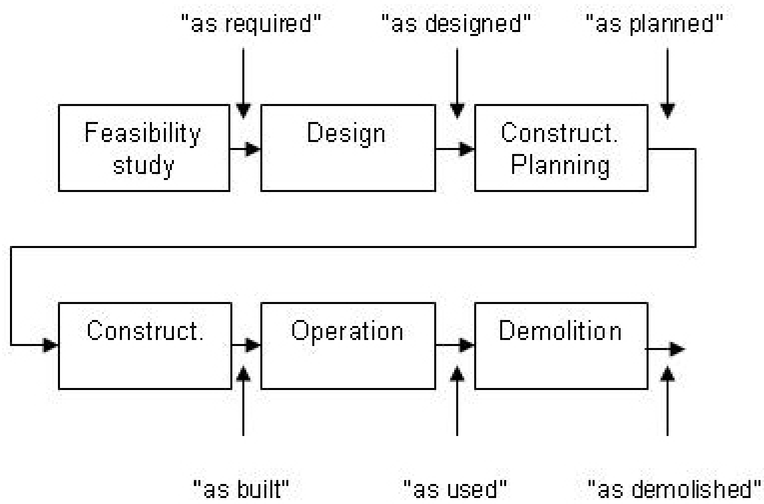

Figure 2. Traditional process description of building life cycle. Adopted from Gielingh's transition stages (Gielingh 1988).

Regardless of the terminology used, the first stage of this strain of theory is an activity to understand the problem. Information about the perplexing factors of a situation is collected from different sources. This stage is the diagnosis, the definition, and preparation to solve the tasks ahead. All terms imply comprehending the problem and an explicit statement of its goals that the problem-solver wishes to attain.

The second stage of the same strain of theory is based on the idea that solutions do exist to solve a problem. Assuming the designer is imaginative and creative he or she finds a number of alternative solutions using imperative and declarative logics. According to Simon (1960), the designer applies the formal logic of design to synthesize any of these alternatives. Under certain favorable conditions, the mind of the designer synthesizes to produce plausible solutions. These preceding ideas fit the intended definitions of *attack*, *search*, and *illumination*.

The third stage of the design process is directed towards validation of the solution relative to the defined goals (Asimow 1962). This includes the selection of the most suitable alternative, if alternatives are available. During this stage, the images and impressions the designer has in mind are given a more formal expression. The unexpressed ideas cannot remain in symbols or words any longer. They need to be documented that others can read and understand them. From a theoretical point of view, the procedure is to express the solution as a hypothesis or mind-model that can be judged by others. A second way of testing is through analytical or logical manipulation or analytical exploration of the consequences of actions based on the proposed solution. The exploration of proposed solutions plays a vital role in the design concepts in architecture and engineering. Regardless of the method of testing the proposed solution, the one that appears to be best is selected. Clearly, this approach is closest to a scientific method and based on *evaluate*, *select*, and *verify*.

Summarizing the various comments and definitions of problem solving, there is consensus that the design process includes at least three stages: the analysis of the situation in which the problem is embedded; the synthesis of possible solutions; and the third, the evaluation of the solutions and, if there are acceptable options, a decision on which option is the best fit. Depending on the complexity of the design process, Asimow (1962, 42-43) suggested to add a fourth stage of revision that improves the chosen solution. Asimow's design process influenced many other design theorists.

Jones (1970) followed Asimow's three stage process, commonly agreed upon as *analysis*, *synthesis* and *evaluation*, which appears as a loose loop over and over again.

Alternatively, as described in his book *breaking the problem into pieces*, *putting the pieces together in a new way* and *testing to discover the consequences of putting the new arrangement into practice*. Jones focused more on the design strategy than its process segmentation. He complained that there is not a “universal strategy,” which applies to all situations. Jones refers to frequently “loose ends of design theory” (Jones 1970, 64). Where Asimow focused on the activity, Jones tried to establish the mental and physical space in which the activities take place. The three stages he distinguished are *divergence, transformation and convergence*. Divergence refers to extending the boundaries of any design situation to ensure that the search space for a solution is wide enough to produce a successful outcome. All methods related to exploring design situations would be part of this category. Jones’ second stage is the transformation, which objective is to establish a framework that is precise enough to permit narrowing down the solutions space to a single design. During this stage the objective, the brief, and the problem boundary are fixed, because constraints are recognized, opportunities taken, and judgment made. Paraphrasing Jones, it is considered the fun part. The last stage of convergence begins once the problem, its variables, and objectives have been outlined. The aim is the reduction of uncertainties until only one alternative remains. This alternative then shapes the final design. This last step is the same as in Asimow‘s model, reducing the range of options to one. The difference is that Jones prefers a solution from which the designer does not have to withdraw, versus Asimow explicitly offers the process of revision and the repetitive loop process.

The difference in the model is an issue frequently raised. Designers suggest what they believe is a final solution too early in the design process. Jones model does happen in reality. However, it is not always helpful to the overall process, since changes constantly take place. Considering the complexity of tasks and constraints, Asimow's process model is closer to practice. A further discussion of this difference takes place in section 5. For this research, the three-step process with the loop is a reasonable assumption that is worthwhile to be tested.

2.2.2 DESIGN AS DECOMPOSING INTO REQUIREMENTS

The previous two researchers, who have been referenced frequently, focus on the design process. Christopher Alexander based his approach on identifying the best components of physical structures of a potential building and its environment (Alexander, Ishikawa, and Silverstein 1977). He posited that structures alter independently to accommodate potential future changes in the environment. Alexander's method consisted of several components.

His procedure focuses largely on the form of the building or component. The model starts with the identification of requirements that influence the shape of the physical structure. Once the requirements are established, an evaluation takes place whether they are independent or not to each other and are recorded in an interaction matrix. This matrix is decomposed and sorted into groups. These groups should be closely internally connected, but only loosely connected to other groups. The groups of components are associated with the initial requirements. The arrangement of the new components forms new physical spaces and systems or are added into existing systems.

Alexander developed many of these requirements and groups over the years, of which some are published in his *Pattern Language* book (Alexander, Ishikawa, and Silverstein 1977). However, the patterns focused mainly on the form language of solutions. An other drawback of his approach is that it is a very time consuming method and not very flexible if other constraints are found later or need to be added during the design process. The solutions achieved through this process are not timeless and provide answers to questions at a particular point in time.

However, it is a much-applied method in research, it is conceptual and does not allow much flexibility. It requires the analyst to recognize all the connections and relationships a priori, a critique Jones (1970) already mentioned. Nevertheless, Alexander's effort of decomposing the procedure into requirements and the relationships among elements is very similar to Thomas Malone's (Malone and Crowston 1994) approach of decomposing the coordination efforts of activities and actors in collaborative projects. This is parallel with a core component of this dissertation at a later section.

Peña and Parshall (2001) have proposed a successful and widely cited design theory. They posited that we need to define the problem before we can begin the design. The environmental constraints need to be analyzed prior to the synthesis. In reality, problems seldom come ready-made with a fine and clear statement of the factors involved. There are rarely clear indications up front for *the* only one solution. It is *ill defined,* if there are many problems or just a single problem, until a situation is investigated. The advantage compared to Alexander's is, it is conceptual and establishes a more flexible framework of stating the actual problem, including constraints.

Peña and Parshall (2001) proposed the "Problem Seeking" method. Opposed to previous authors, they separate the process only into two overall phases. The first phase is the *Analysis* or *Programming* phase and the second is the *Synthesis* or *Design* phase. Problem Seeking argued that to produce a great building, all surrounding factors must be defined, as in "Pattern Language," before the project can be passed on to the actual designer. "Good buildings do not just happen. They are planned to look good and perform well. […] Programming the requirements of a proposed building is the architect's first task and often the most important" (Peña and Parshall 2001, 12). The ordering principles concerning programming, the first phase, are these five concepts: establish goal, collect and analyze facts, uncover and test concepts, determine needs, and state the problem.

The Problem Seeking approach is an attempt to define design as a structured search process. This approach argues that the steps taken towards producing a quality product are limited to information processing capacity of the designer, a limiting factor Alexander already encountered. Hence, the designer needs knowledge of all parameters influencing the building projects prior to the design process. In the latter method, the limited capacity is compensated by allowing multiple input channels to capture all parameters. Because then the outcome of the first phase, the "problem definition" becomes more stable than if only one input channel would be available, defining the solution space. The approach is simple and comprehensive at the same time. It applies easily to different building types and sufficiently enough covering a wide range of factors that influence the design of buildings. It is more of a methodology than Alexander's approaches where knowledge about the situation is more important than the process of getting this knowledge. In addition, the underlying principle could be applied to many professions; it is best applied to architecture with its focus on rooms, buildings and cities. Peña and Parshall argued that the analyst, or programmer as he is called in an architectural context has often different mental processes than the designer. Therefore, the two stages should be separated. The process is considered to have the best chance of a successful final building product according to the Peña, if the designer receives all parameters prior to begin of the synthesis phase. The reasoning for addressing the various methods of design theories is that for a solid interpretation of the data all options should be know before any conclusion can be drawn. Since one project in this research in particular has the tendency to use the Problem Seeking method, it is covered in the literature review.

2.2.3 REFLECTION IN ACTION

The previous sections explain very technical and rational design theories that constitute the first strain. Donald Schön (1983) criticized technical rationality and "mainstream design methodology". His theory is a nucleus for the third strain. He stated that design methodologists restrict themselves to terms of generalities about design processes or decomposition. He argued that every design artifact is unique, a "universe of one" (Schön 1988, 181), and therefore should not be judged by a standard approach. He criticized that the structure of the design tasks and the crucial problem of the linking processes of the design tasks are secondary. Schön discussed the lack of attention paid to specific design situation. A key concern is the evaluation of the uniqueness with which each task should be tackled. Frequently skilled designers rely on their *professional* *knowledge*, but the individual problem remains not described. Schön considered this attention upon uniqueness the core and artistry of design practice and was dissatisfied with a common treatment of steps in a process. Paraphrasing Valkenburg and Dorst (1998), Schön found fault with the prevalent analytical framework for failing to describe these activities, and regretted that the solving of unique design problems therefore cannot be taught in the professional schools.

The concern of the reflection in action theory is the development of knowledge by the designer. Knowledge builds up in a cumulative fashion and carries over from one design episode to the next. If designers only frame situations and shape practice through rules, which carry over from one project to the next, then they would never create something new. As we know, this is not the case in realty; they do create constantly new solutions. Therefore, Donald Schön's scheme is based on the actions and the ability to make the right decisions about those actions. The designer, who reacts upon his or her own actions or decision-making, reviews the results of these experimental actions. The final design is a result of this interaction. This actual concept of the reflective practitioner carries significance beyond the field of architecture. The ACM (2005) digital library provided over 50 references on the term "reflective practitioner" and the ERIC educational database (2005) provided also more than 50 articles. This theory provides a solid explanation of how professional activity takes place, if professionals have to cope frequently with surprise and uncertainty on their design endeavor.

Valkenburg and Dorst continued and analyzed Schön's reflective practice. Both separated the *reflective conversation with the situation* into four types of activity, designers work by *naming the relevant factors* in the situation, *framing a problem* in a certain way, *making moves toward a solution* and *evaluating* those moves (Valkenburg and Dorst 1998, 251). They labeled the four groups of activities: *reflection*, *framing*, *moving* and *naming*. Reflection being the conscious and rational action that can lead to "reframing the problem (when the frame is not satisfactory), the making of new moves, or attending to new issues (naming, when the reflection leads to satisfaction)" (Valkenburg and Dorst 1998, 254). The reflection is an evaluation of what the designer has produced. If the designer is not satisfied with the produced result or synthesis, he or she would have to re-synthesize. Schön's model of the reflective practitioner provides a lens through which I may interpret the results of prior analyses, identify possible measures of reflective practice behavior, or determine new types of analyses for the existing dataset. Schön's work suggests two important descriptors for the reflective practitioner: recognizing the importance of problem setting and listening to situation's back-talk (Adams, Turns, and Atman 2003, 281). Both strains document similar cycles of design processes. The difference is that the first one has a more scientific and logical approach. Judgment and evaluation are based, as Simon suggests, on utility theory and statistical decision theory. The second is more creative and reflective upon the process and its results itself, the reflection upon what has been created. Schön emphasized that practitioners behave within their environmental settings, which affect their problem solving.

However, the setting of the research data in this study is not always known because neither actual participant nor project team members were directly observed. The setting for the cases addressed in the dissertation research can be guessed.

The last design model goes beyond the physical pieces of buildings, it relates to the result of the conglomeration of elements. The *Building Systems Integration* model establishes a system based on building performance criteria. The six building performance mandates are the spatial performance, including the space layouts, service spaces and occupancy control factors (Rush 1986). It also addresses the thermal performance that could be considered the temperature, humidity and air flow and the indoor air quality, which targets the fresh air and air pollution controls. In addition it covers the acoustical performance; the visual performance tries to ensure light levels, colors and visual information; and the last mandate, the building integrity covers the structure, the envelope and interior systems performance (Hartkopf, Loftness, and Mill 1986).

2.2.4 INDUSTRY DRIVEN PRODUCT MODELS

A different approach to modeling or documenting the design efforts is using product models. Product models focus on building elements and not on cognitive or operational processes as described above. The number of such product models is currently very large and far from homogeneous. Several attempts have been made to establish cross discipline accepted models. Over the last decade designers and engineers have started to look more closely into modeling the design process from a project model perspective. This has the underlying assumption that with sufficient information, product modeling might be able to simulate the design process. Many of the users and researchers aim for one product model that covers the entire project life cycle, but in a fragmented industry like architecture and construction this is very difficult to obtain (Luiten, Tolman, and Fischer 1998) .

Eastman and Augenbroe are among the leading researchers within the AEC industry on project modeling and data classification (Eastman 1999; Verheij and Augenbroe 2001). They investigated and developed their models largely together with construction industry. Recent studies by Eastman are models for data interaction in the global steel industry, allowing *Computer Controlled Manufacturing* (CCM) based on design data without reentering any information (Eastman 2004). A second ongoing study they are conducting is in cooperation with the precast concrete industry.

Another currently common model is the *Construction Specification Institute* model (CSI 2005). The CSI model groups all tasks and physical pieces in a building project into 16 groups. These groups have several sub layers and can produce an accurate cost schedule for a building, if combined with current RS Means cost data. The level of detail is of such fine granularity that each different nut and bolt can be described. However, it might be questionable whether it is economically useful to get to this level of detail.

The *Standard for the Exchange of Product* model data (STEP) is an international product data standard. It provides complete, unambiguous, computer-interpretable definitions of the physical and functional characteristics of a product throughout its life cycle (NIST 2005). Product modeling tries to manage the vast amounts of information and knowledge in the design industry. It aims to re-use information from previous projects and experience (Tolman and Stuurstraat 1999; Tolman 1999). In contrast to the design activity studies, it focuses on the physical elements and not on the how to select them. It is a much broader standard than data interchange standards such as IGES (Initial Graphics Exchange Specification), since it is intended to support product data throughout the lifecycle of a product including engineering and manufacturing. STEP has the capability of implementing and sharing product databases and archiving beyond a neutral file sharing. Today, building information is stored in different systems, often with little or no integration and with a great deal of data redundancy. For example, engineering drawings may be maintained in a proprietary CAD system format, but information on product structure, manufacturing processing and configurations are contained in different systems stored in different formats. STEP alleviates this problem by providing a single product-data storage-standard that integrates the data. This model has also been used in recent research projects by Faraj et al. (2000) and Arnold, Teicholz and Kunz (1999).

Similar efforts are currently put forward by the *International Alliance of Interoperability* (IAI 2004). The IAI's intent is to provide means of transferring accurate building data models among computer applications, like CAD, without loosing any information. The IAI began establishing Industry Foundation Classes (IFC) in 1995. IFCs are data elements containing the relevant information about parts of buildings and processes. In 1999, the IAI developed the concept further and established common schema definitions for AEC elements via standard XML formatting language. They created aecXML within a relatively short timeframe, by getting producers and consumers together. The current aecXML schemas are based on well-defined business cases to establish a common data format to transfer specific information over the Internet free from human intervention.

All these building models contribute to an understanding of building information models and are part of recent developments in the building industry. However, all assume that the participants are willing to perform fruitful collaboration and are well versed in information technology use. The next sections will indicate how to code these design activities.

2.2.5 CODING DESIGN ACTIVITY

One of the most prominent coding schemes is a development of Purcell et al.'s (1996) study for the Delft design activity workshop. Purcell's had increased the number of sub-categorizes in comparison to their earlier work for the workshop, but studies have proven that it was too fine grained and it was frequently difficult to distinguish between analyzing and evaluating a problem or solution. Later, Gero and McNeil (1998) revised Purcell's protocol in an attempted to bring more structure to the amount of data produced in protocols without distracting from the richness of the data (Purcell and Gero 1998). Since architects tend to redefine constantly their design, differentiation is difficult between analysis and evaluation. Hence, Gero merged the analysis of problem and the evaluation of solution into the analysis of solutions in his 1998 study. This reduced the categories in the design activity classification to *synthesizing solutions*, *analyzing solutions*, and as an outside category, *explicit strategies*.

Coding Scheme of Purcell et al.

The two most influential studies for the development of the coding in the WBCS study were Purcell et al's (1996) and Al-Qawasmi's (1999) studies. Purcell et al. applied a coding scheme, where each event in a design episode is defined over three broad classifications. The first two deal with the problem to be solved. This is the level of abstraction (systems level, sub-systems level and detailed level) and the second is the form of reasoning or knowledge representation (function, structure and behavior), which was developed by Gero (1990). Purcell et al. correlated this representational model with the actual design activity of each episode, described through the third classification. This classification is the strategy the designer uses to solve the particular activity. Since the strategy is problem independent, it is appropriate to compare this classification type across different studies, such as the WBCS study. Purcell et al. generated the coding scheme based on the theory that Gero developed earlier. This last classification has the most impact on the dissertation study, since it addresses the design activity as a project independent process. It is the primary focus of the following discussion and comparison with the study below.

Coding Scheme of Al-Qawasmi

The second study is Al-Qawasmi's (1999) research. He investigated the correlation between the type of collaboration channel and the design activity itself. Both are part of the four elements of communication under investigation in this dissertation (Shannon and Weaver 1998). Twenty teams of two architecture students were given the very common architectural task of designing a simple house. The pair of participants was separate into two rooms and could only collaborate or communicate through a given set of networked media. Their two-hour interaction was recorded on videotape.

The coding scheme has two main classifications, the types of channels used, which can be application sharing, whiteboard, chat, file transfer, video, and audio. The second classification is the design activity, which is divided into categories of *analysis, synthesis*, and *evaluation*; and *coordination* and *other activities.* Time is a continuous variable beyond both classifications. The channel usage is defined by technology and can be objectively measured as an unambiguous system. The communication content measures are complicated and based on a less objective coding scheme, which is the target of the comparison.

Al-Qawasmi developed his coding scheme based on previous theoretical coding schemes and emerging categories from data, he analyzed, similar to Purcell's approach. On a "theoretical level, the coding scheme is based on the analysis- synthesis- evaluation theory of design" (Al-Qawasmi 1999, 59).

Comparison of Existing Coding Schemes

The common categories are: analysis, synthesis, evaluation, but each research added additional individual categories to the classification. Purcell et al.'s study had the classification of *explicit strategies*. The second added the non-design related activities *coordination activities* and *other activities*.

Purcell's *explicit strategies* contain references to external domain and application knowledge. This category is valid in a study where the actor is a professional and experienced designer. He has more tacit knowledge than a student does, conducting a similar design experiment does. This is an issue to consider in the WBCS study, because it deals with professionals. It might not be within the design activity but needs to be addressed in the content coding schemes. Regardless, the researcher must be aware that it is impossible to judge this tacit knowledge, because the actor might integrate it into his automatic design behavior without letting the observer know.

Al-Qawasmi's *coordination* category accounts for 5.6% of the activities in his study. The description defines coordination activities as participants assigning responsibilities and outlining tasks and requirements, they have to accomplish. Because Purcell et al. investigated a single designer; he might not have needed that classification. It might have been different, if Purcell et al. would have chosen to analyze the alternative tape provided to the researchers at the Delft Workshop with three designers as a team (Purcell et al. 1996). The category of *other activities* Al-Qawasmi provided, covers monitoring of other participant, and interface specific tasks (dealing with issues of commands, connections, menus and tools to achieve optimal collaboration). About 30% of all activities fall in this category. Rather than simply labeling this category *other activities*, a label such as *interface issues* and *monitoring* would have been more descriptive. In particular, in a synchronous collaboration environment, it is justifiable to observe monitoring or waiting for responses. Purcell et al. assigned his single designer study an "X" to phases of *no design action*, like thinking or receiving explanations regarding the task.

Consistent through all categories is that Purcell et al. has a sub-category of postponing tasks, a category Al-Qawasmi has not provided. The paper does not provide indicate whether this category was actually assigned to any task. I assume he provided this subcategories, because designers often use the reflective approach and come back to a previous idea at a later time to redefine it (Alexander, Ishikawa, and Silverstein 1977). Al-Qawasmi differentiates within the category of synthesis the sub-categories of spatial and functional relationships and sub-categories of evaluation of spatially, functionally and specification related solutions. In the Purcell et al.'s study, these sub-categories are merged into one evaluation and one synthesis subcategory. Since Al-Qawasmi was investigating different media channels, it is an interesting approach to correlate types of perceptions to types of channels. A theoretical reasoning to provide these sub-categories is media richness theory that Al-Qawasmi refers to frequently. Each of those sub-categories accounted for about 2 to 3% of total activities. This low percentage brings up an issue Rosenman, Gero and Maher (1994) point out that too many (sub-) categories might be too complex, potentially masking relationships and patterns in the data. It is difficult to validate findings, if the total count in a category is too low.

2.3 COLLABORATION MECHANISMS AND TECHNOLOGY

As the industry globalizes, collaboration becomes mandatory. 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). It is not sufficient to communicate; the participants have to establish a common space for their interactions and their work. The space is not a physical space, but is rather a medium through which the team members communicate. This communication is only then successful if all agree on a common understanding. Participants can communicate with one another directly through the medium of shared space.

What is collaboration? The concept of collaboration is an attitude and an interpersonal process that embodies cooperation and the spirit of working together. Professionals with divergent or similar training, who work within a framework in which they come together, collaborate. This team behavior can provide quality, comprehensive, and efficient service. Based on the thought of a team working together effectively, collaboration can be expressed as a process of value creation towards problem solving, given a set of constraints, such as limited expertise, time, financial constraints (Lorenz, Mauksch, and Gawinsky 1999).

Nevertheless, this definition of collaboration is still very broad and depends on the individual applying the term. A common denominator of our understanding of collaboration is that "c*ollaborative success can […] be achieved when we have accomplished something in a group, which could not be accomplished by an individual*" (Kvan 2000, 410). Collaboration is a joint problem solving that is working together with shared goals. These goals are necessary for the team to find a satisfying solution. Collaboration connotes a more durable relationship and requires full commitment to the mission. Summarizing, for the remainder of this study:

Collaboration is defined as the interaction of two or more people towards a common objective within a set off constraints.

Various technologies assist in collaborative efforts. Computer Supported Collaborative Work (CSCW) and Information and Communication Technology (ICT) are part of the collaborative process and essential pieces of the literature review. In the architecture, engineering, and construction (AEC) industry WBCS are such online collaborative tools. They are overlapping with many of the CSCW issues and technology concerns documented according to Alshawi and Ingirige (2003).

The question, which technology fits the tasks best is difficult to answer (Beniger 1990; Zack and McKenney 1999). A sound judgment regarding which information technologies are available to support collaboration and which is most suitable is not easy. The range of collaborative technologies and available applications is vast and depends strongly on the area of application. The technological applications have been broadened from the originally supporting workgroup or team level to organization-wide functionality such as using Information Technology (IT) as a document management system and knowledge repository.

Team interaction involves more than discussion and information sharing. Certain aspects of group interactions may improve the outcomes (process gains), while others may impair outcomes (process losses) as Nunamaker (1997) explored. Group Support Systems (GSS) provide features that foster the team collaboration through anonymity, equal participation, reduced domination and group memory capabilities that "directly effect processes and outcomes and that are missing or severely limited in other computer-based collaborative support," (Nunamaker 1997, 359).

2.3.1 ELEMENTS OF COLLABORATION

Effective collaboration depends on a number of factors, some more important than others. The significance depends on the environment in which the collaboration takes place. The requirements for effective collaboration include a common purpose, mutual respect, shared paradigm, effective communication, co-location, and compatible incentive (Lorenz, Mauksch, and Gawinsky 1999). The next paragraphs describe these requirements in more detail.

Collaboration requires *mutual respect* for each other. It is essential to respect each other like in any relationship, but it takes time to develop a good working relationship. “Successful experience promotes respect, but awareness of limitations foster shared responsibility” (Lorenz, Mauksch, and Gawinsky 1999, 69). Over time, trust grows and respect increases, even faster if projects are more complex.

The participants must recognize a *common purpose*. Different individual goals may exist, but may not be mutually exclusive. When different goals are the source of conflict, the participants must review their short-term goals and place the overall goal above their individual short-term goals. All participants are aware of the common goal.

Shared paradigm is an element of effective collaboration. It enables an easier transition to foster collaborative relationships. Nevertheless, the individual ideas cannot be mutually exclusive. Lorenz, Mauksch, and Gawinsky (1999) state that having a shared paradigm can prevent power struggles among collaborators. If participants share similar ideas, it is more likely that they can work together without competing against each other.

Clear communication promotes effective collaboration. Communication varies in style and form. Recognizing these differences facilitates better communication. This includes periodically updating each other in regards to tasks, progress, facts, and concerns.

Researchers outlined *co-location* as a condition for collaboration, because proximity enables easier exchange of information (Kraut et al. 2002). This is an interesting question. Since the more recently collaborators can technically be not in the same location anymore. Globalization and specialization of tasks made it impossible. On the other hand, if there is no co-location other means must provide capable compensating for the absence of co-location, such as CSCW.

The last condition is of straight financial concern, mostly to the individual. Each participant must feel *adequately compensated* for the work he or she is contributing. Barnard (1968) stated decades ago that the incentive scheme is the core motivation for individuals to work productively. Participants in collaborative environments often feel uncomfortable sharing competitive knowledge, if they do not receive proper credit for the contribution towards the common goal (Williamson 1995; Haldin-Herrgard 2000). Within the realms of this study, the issue of compensation is not addressed, since the data provided did not include such information. The elements described above apply to all modes of collaboration.

2.3.2 MODES OF COLLABORATION

DeSanctis and Gallupe's (1987) developed a simple taxonomy that categorized the collaboration technologies into a time dimension (synchronous / asynchronous) and space dimension (same location / different locations). These four matrix cells in Table 1 provide a good understanding of the scope of collaboration and their differences. However, several technologies cover more than strictly one cell. Organizational work is rarely restricted to one cell alone in particular in an expanding economy of increased project complexity.

Table 1.
Time-space matrix for classifying collaboration technology. Adopted from Munkvold (2003, 9).

	Synchronous	Asynchronous
Co-location	Electronic meeting systems Face-to-face	Email Calendar and scheduling system Document management systems Electronic bulletin boards Workflow management systems
Distributed	Audio conferencing Data conferencing Desktop conferencing Instant messaging Telephone call Video conferencing	Email Calendar and scheduling system Document management systems Electronic bulletin boards Web-based team / project rooms Workflow management systems

Synchronous Collaboration

The synchronous collaboration in design is probably a very common form of collaboration. In the traditional office environment, the design teams are arranged around one physical area. In addition, people are used to it from the times, before technology ruled. In architectural design, meeting the team members and sitting together around a table to present and discuss design issues is in every designers' mind. Often designers execute preliminary sketches during the meeting in the group, before individuals work them out later. In terms of location, the face-to-face collaboration normally involves meeting in a common venue such as a physical meeting room, and participants engaging in spoken discussions. An example could be an initial meeting between an architect and a client for a project briefing session.

In the past and still today, these meetings take place around a conference table, but technologies such as telephone, video conferencing, fax, liveboard, and computer-mediated meeting spaces have made it possible to hold meetings for synchronous collaboration among design team members, who are geographically dispersed. The most referenced term within architecture in relation to team work in geographically distributed teams is *virtual design studios* (Gross et al. 1998; Maher, Simoff, and Cicognani 2000; Biuk-Aghai and Simoff 2001; Vasquez de Velasco and Jimenez 1997). Other examples for synchronous distributed collaboration technology are simply telephony, computer-mediated conferencing, video conferencing, electronic group discussion facilities.

Asynchronous Collaboration

The other mode of collaboration is the group working at different times. Asynchronous (co-located) collaboration takes place in every office. A common medium is the simple message at the bulletin board in an organization. Whenever a person walks passed the board, in the morning or evening, other notes might be displayed. In situations where the participants are at different locations, asynchronous distributed collaboration modes involve communication via the post e.g. periodic letters, news bulletins, fax machines, telephone’s voice mail, pagers, electronic mail transmissions. Or in architecture terms, redlines and markups are traditional architectural techniques (Demkin and American Institute of Architects. 2005; Wakita and Linde 2003). As a caveat it has been indicated that collaboration across distances of over 100 feet in an office are more like remote-located teams. It has similar interaction behavior to collaboration across the Atlantic (Kraut, Egido, and Galegher 1990).

Short-term asynchrony enables people in different time zones or on different schedules to participate at their own convenience. The advantage is that not everyone must meet at the same time to conduct an online-design meeting. Participants can access information and *meet* at their own convenience. Secondly, long-term asynchrony enables the collaboration of designers over an extended design calendar. Designers who join the team later or who where temporarily detached from the project and come back can still access earlier documents, since theoretically all information over the life cycle of a product is kept. This long-term asynchronous collaboration makes use of the archive or repository functions of WBCS. In theory, team members can make use of stored expertise, corporate knowledge, and other knowledge acquired on previous projects. In architecture, drafting standards, block libraries, detail libraries and office procedures can enable a kind of collaboration with anonymous parties (Stitt 1980; Edwards 1984). The question is how well they store, for example, design rationale (Gross et al. 1998, 468; McCall and Johnson 1997). In addition, one can only retrieve what has been fed into the system. Hence, it is still very user dependent. While there are tools such as video conferencing that support distributed synchronous collaboration by enabling 'virtual co-location' of project team members, there are very few design tools that adequately support distributed asynchronous collaboration.

2.3.3 COMPUTER MEDIATED COLLABORATION

Kayworth and Leidner (2000), Pawar and Sharifi (1997), and Huang et al. (2003) have been investigating the issues of virtual team building. Their research on the use of Web-based systems in design using similar mechanics to the study presented here. However, the sample size was smaller than in this dissertation. In addition, the data in previous research was produced primarily through synthetic experiments, whereas this study is a natural experiment based on quantifiable data. Huang et al. used general knowledge regarding actual design practice and described in theory how collaboration can take place. Huang et al. found that collaboration can be more effective under the conditions that clear goals are set in advance of the collaboration. All team members must work purposeful towards achieving this goals.

Collaboration technologies can be differentiated by the modes in which they operate and by their functional models. I will refer to a recent definition of collaboration technologies that includes the three functional models of *communication technologies*, *shared information space technology*, and *coordination technologies*. In addition there are two special classifications Munkvold (2003) specifies: *meeting support technologies* and *integrated products*.

Communication technology includes E-mail, instant messaging and audio/ video conferencing. It includes asynchronous and synchronous technologies that support interpersonal communication across geographical distance and within the same office regardless of time settings. The differentiating functional characteristic is that communication technology does not process any information. All of these technologies are commonly available and widely used on a daily basis, except perhaps the video-conferencing.

Shared information space technology relates to the production and manipulation of information objects like drawings and documents and objects for creating virtual interaction spaces (Munkvold 2003). The category includes document management systems, Web-based team and project management sites, data conferencing, application sharing, and electronic bulletin boards. Hence, particular attention is given to these, as the WBCS, which are the focus of this research, are considered a shared information space technology. The technologies support work across time and across distance, except for application sharing, which requires users on both ends at the same time.

Meeting support technologies, known as electronic meeting systems, provide meeting support in particular for corporations. The functionality differs, but most include agenda specification, procedural guidance, electronic brainstorming, recording, and storage. In an architectural setting, they are not common (Munkvold 2003, 17). None of the systems studied during this AEC research has provided any of this functionality. The AEC industry is still behind in the use of this technology, compared to manufacturing or high-tech industry.

Between these three categories are hybrid products. One of them is c*oordination technology*, which is a workflow management systems, calendar, and scheduling systems. This is a system very similar to a MS Outlook, when used to the extent possible, including all functions provided. This system supports the act of managing interdependencies between activities performed to achieve a common goal (Malone and Crowston 1990). It is an industry independent functional model, since coordination is mandatory for any successful teamwork project. It is important to indicate that this technology exists, but also outside the AEC. Part of the research focuses on the work task of coordination during architectural and engineering work, but none of the project has used such a technology. Huang (1999) predicted that firms need to focus more on the inter-organizational collaboration to remain competitive and to leverage the knowledge potential. A solid coordination model would enhance the technological development towards better communication, yet there is no architecture related model of coordination established. A study of the work tasks related to coordination is necessary, to establish a solid coordination model for the industry.

The last crossbreed is *integrated products*, such as collaboration product suites, integrated team support technologies and e-learning technologies. They are a combination of communication, shared information space, or meeting support technologies. Typical applications are Microsoft Exchange or Lotus Notes (Lotus 2003). The e-learning suites are an integration of several applications used in the pedagogical environment and in corporations. Such e-learning suites use IT for supporting instructional and learning processes. They enable synchronous and asynchronous learning as shown in Figure 1. An example for e-learning is Vista in an educational environment and Lotus Learning Space and WebEx (WebEX 2003) Training Center for corporations (Lotus 2003; WebEX 2003).

The remainder of the study discusses the online project collaboration sites (WBCS) as a shared information space. Operating across time and geographical distances, users can access information and can contribute 24 hours a day and seven days a week. A WBCS also has the advantage of being able to operate as long-term and short-term asynchronous support tool (Gross et al. 1998; Munkvold 2003).

2.3.4 EXAMPLES OF COLLABORATION IN AEC EDUCATION

The effectiveness of Information Technology (IT) depends on the technology itself and largely on the environmental setting. Over the past decade, architecture schools have studied collaboration and new technology in the classrooms. Several conferences have focused on this topic, such as eCAADe, CADD futures and ACADIA (Clayton and

Vasquez de Velasco 2002; Kalisperis and Kolarevic 1995; Seebohm and Van Wyk 1998; Vries, Leeuwen, and Achten 2001). The following example was an architecture design studio, which used editable Webpages to establish an exchange among graduate student teams and external critics (Craig and Zimring 2002). The collaborative application was a Webpage that allows insertion of text and comments into existing sites. It also allowed adding new pages to it, by all users. It did not indicate who submitted comments or criticized whom. Students designed a courthouse, by gathering information about courthouse design and then developed a design concept. They submitted their design ideas through Webpage in primarily textual form. The external reviewer added comments to the Website or a new Webpage. The shared information space allowed an unstructured way of helping each other, by omitting the information of the author. The concept is similar to brainstorming software, omitting names and allowing asynchronous interaction, to reduce the pressure on the designer from the critic. Brainstorming software allows participant to see what others present, without having names posted. In a second step they allow to group and to prioritize the ideas. This did allow students to comment on each other's projects without being judged directly. The strength of this online system is reduction of social constraints such as evaluation apprehension. Evaluation apprehension could arise in studios, if students think that others in the group know more than they do and are hesitant to comment on others. The are concerned by raising the wrong question, others could identify their lack of knowledge. This online community was designed around the idea of sharing and discussing design issues. The research produced no evidence, that this would hinder the successful architecture (Craig and Zimring 2002).

Craig and Zimring argued that the system suffered from the failure of students to buy into the system and comment on each other's work. They did not see the benefit for them because they did not share a common goal. Despite the fact that *co-location* is frequently considered to favor collaboration, students preferred to talk to each other face-to-face rather than commenting online.

Frequently, the weaknesses of collaboration technology related more to social-technical issues rather than purely technology deficiencies, if organization and technology are not adopted to each other (Hollingshead and Contractor 2002). One weakness in the given example is a technology limitation. The system relied primarily on textual exchange. Architecture and design require technology to support visual exchange such as drawings and documents to collaborate effectively. Authors like Kayworth and Leidner (2000), Pawar and Sharifi (1997) and Huang et al. (2003) have conducted similar studies. However, these studies took place in an education setting. In contrast, while these examples collect data through synthetic experiments. The dissertation research makes use of a natural experiment.

2.3.5 IMPACTS OF COLLABORATION TECHNOLOGY

Computer-Supported-Collaborative-Work (CSCW) involves both the technology and the social side. Literature describes the computer as a medium for communication. Hollan and Stornetta (1992, 120) suggested that *Information Communication Technology* (ICT)'s could be used to create wholly new forms that serve as "athletic shoes to enhance our performance," to accomplish what previously was not possible. At the same token, they argue that this goal is only possible if the technology perfectly mimics the face-to-face approach.

Other authors have stated that the success of ITCs relates to media richness. Daft and Lengel's media richness suggested that success depends on information richness of channels, featuring cue variety, feedback, and message personalization, as candidate needs (Daft and Lengel 1986; Daft, Lengel, and Trevino 1997). Media richness theory suggests that communication media can be characterized in terms of *richness* and that richness influences the media choice and communication process. It provides good explanations for many communication related studies, but more recently this theory is questioned as having not a significant impact (Rice 1992) nor being able to predict the selection of the media (Fulk, Schmitz, and Steinfield 1990). A more recent approach to explain the relation between technology and user is DeSanctis and Poole's (1994) adaptive structuration theory. The purpose of ICTs is supporting the company's efforts to achieve its business goal. Yates and Orlikowski (1992) and Argyris and Schön (1996) documented how these technologies influence our behavior. Rules and users behavior have evolved over generations. Investigation is required to study communication technology regarding how the technology has influenced the work process and the user, or vice versa.

The use of electronic systems has pros and cons. Sproull and Kiesler (1991) indicated that electronic meeting systems allow more equal amounts of contributions across participants than in face-to-face meetings. One particular person may dominate face-to-face meetings and not everyone is inclined to contribute equally (Kraut et al. 2002). This is parallel with the *who talks first* effect; participants with a lower hierarchical rank are more frequently communicating first in an electronic system than they would in a face-to-face meeting. However, it has been opposed by Olson et al. (2002), arguing that the benefits of collocation in meetings outweigh the distance. Gestures, non-verbal communication, and tacit knowledge are hard to express and cannot be transferred well over distance media. They also reported that artifact sharing is difficult (Olson and Olson 2000). Other multimodal interactive exchanges are problematic (Kraut et al. 2002). It is obvious that the technology cannot substitute directly for technology-less communication. Therefore, the use of IT in any industry must be carefully evaluated regarding the ability of the software to match the organizational requirements and the potential benefits for the organization itself.

2.4 COORDINATION THEORY

Technology integration has such a potential to change the way organizations communicate, it also may change how they coordinate. Because coordination is so important, it is essential to know how firms coordinate their activities (Kling et al. 2001). Regardless, the distinction between coordination, collaboration and cooperation or even communication is not trivial, if even possible. Often cooperation refers to as the collaborative process in which actors focus on a shared problem and try to negotiate a mutually acceptable way of solving it (Kling et al. 2001). A high level of successful projects requires not just collaboration. They also require that the actors and actions leading to the collaboration are well coordinated.

Coordination theory focuses on interaction among people and covers multidisciplinary teams and information exchange among team members (Malone and Crowston 1994). It is essential in distributed teams to maintain the team's awareness of events (Crampton 2001). The theory provides explanation of changes due to processes and demands. An examination of WBCS can take place in relation to the changing context, which in architecture may be seen in the different project phases. To better understand each of these phases, they are split into their individual activities, which are then reconnected or rearrange to improve the original process (Huang 1999).

2.4.1 PREVIOUS STUDIES ON COORDINATION

The ideas and concepts behind coordination theory have been around for years. Many fields have contributed to the development of coordination theory, such as computer science and organizational science. An all-inclusive definition of fields related to coordination is undesirable, since depending on the context some are more applicable than others are. Drawing a distinct boundary is not helpful. Nevertheless, there are a number of examples of previous work related to coordination theory, which are relevant to this research.

Winograd and Flores have developed a theoretical perspective for analyzing group action (Flores et al. 1988; Winograd 1987). The basis of their study relies on ideas from linguistics about different kinds of "speech acts." These acts can be requests and commitments. The linguistic approach was the primary basis for designing the *Coordinator,* a computer tool that assists people in placing requests and keeping track of commitments to each other.

The second study of interest, in relation to this dissertation, is based on organizational theory about flexible structures, called *adhocracies*, a term defined by Mintzberg in his book "The structuring of organizations: a synthesis of the research" (Mintzberg 1979, 431). Mintzberg explained the concept of adhocracies as work groups, which are arranged on often short notice. Their team members often work together for the first time. Most of architectural businesses today can be considered adhocracies: with high horizontal job specialization and a tendency to group specialists in functional units. These groups are arranged in small market based project teams. The concepts of adhocracy lead to a concept for software, the *Information Lens*, a system for helping people sharing information in organizations (Malone, Lai, and Grant 2001). The three examples share that they investigated the efforts to improve coordination through IT.

Coordination theory is trying to fill the lack of a coherent body of theory regarding coordination. There are multiple disciplines, which can contribute to coordination theory and many of which could benefit thereof, but none is a complete enough to describe the whole process of coordination. The process of coordination is considered a more structured process than collaboration (Crowston 2003). It is a semi-formal relationship and understanding of compatible missions of individual contributors, requiring good planning and often division of roles: who is doing what. It inherently relies on established communication channels. Studies have shown that the implementation of IT based coordination technologies is much easier when the new coordination problem does not face major institutional demands (Kling et al. 2001). The more complex the coordination task gets, the more difficult the coordination technology necessary to solve the tasks. It cannot be seen as a simple solution to a difficult problem. Kvan (2000) states that the appropriate resources need to be made available to participants and they need to be rewarded mutually, an issue Barnard (1968) already raised early on, to ensure a successful outcome.

Since coordination is a widely defined term, Merriam-Webster (2005) lists the following two definitions: "the act or action of coordinating," or better "the harmonious functioning of parts for effective results." Other groups and dictionaries provide similar definitions. But a more appropriate definition for the purpose of the study is "*the act of working together harmoniously*" (Malone and Crowston 1990, 376). This definition is at the starting point of the coordination theory and describes the principles of how activities can be coordinated.

2.4.2 MALONE'S THEORY

Coordination theory aims to explain the field of computer supported cooperative work and addresses the potentials and problems related to coordination (Malone and Crowston 1990). The decomposition of goals, activities and relationships of task is at the center of the theory. In a second step, it investigates how these tasks or activities relate and link to the actors. The theory explains the resource allocation among different actors and their information sharing that is needed to achieve the overall goals.

Coordination is "the act of working together harmoniously" (Malone and Crowston 1990, 358) and deals with one or more *actors* that perform a task towards a common goal. The word *harmoniously* implies that the activities connected to each other are dependent. Therefore, they must be performed to be pleasing or towards achieving the common goal. Malone refers to these goal relevant activities as *interdependencies*. The relationships and their level are shown in Table 2.

Table 2.
Components of coordination (Malone and Crowston 1990, 378).

Components of coordination	Associated coordination processes
Goals	Identify goals
Activities	Map goals to activities
Actors	Select actors, assign activities to actors
Interdependencies	Manage interdependencies

If there is no interdependence, there is nothing to coordinate. Coordination processes are kinds of interdependencies. Possible examples of coordination are the requirements and prerequisites, such as the output of one activity is required by the next activity. Furthermore, shared resources make it necessary to coordinate, because they are required by multiple activities. A trivial architectural example would be the order of building components; the columns need to be there before the ceiling can be put in place.

Identification of the different coordination processes requires knowledge regarding the underlying processes. Table 3 provides linkage of the process levels, its components and its examples. These two tables document the core definitions of the coordination theory.

Table 3.
Processes underlying coordination.

Process level	Components	Example of generic process
Coordination	Goals, activities, actors, resources, interdependencies	Identifying goals, ordering activities, assigning activities to actors, allocating resources, synchronizing activities
Group decision making	Goals, actors, alternatives, evaluations, choices	Proposing alternatives, evaluating alternatives, making choices
Communication	Senders, receivers, messages, languages	Establishing common languages, selecting receiver and routing, transporting messages and delivering

2.4.3 APPLIED EXAMPLES

Researchers posted many models of organizations. One example is the organizational contingency theory (Galbraith 1973; Mintzberg 1979). It assumes that there is no general solution to organize an organization and any way of organizing is not equally effective. It focuses on the factors the choice of organization depends upon. This is very capable of qualitative predictions of processes, but according to Levitt et al. (2001) it cannot predict organizational performance. Engineering methods, such as the *Critical Path Methods* (CPM) can model time and durations, but tend to underestimate organizational or task complexity. Hence, from an AEC viewpoint, structuring an engineering process based on dependencies can be successful. The *Virtual Design Team* (VDT) focuses on the restructuring of existing processes by applying sequential, informational and failure dependencies, similar approach as coordination theory (Christiansen 1993). This is reason enough to test it for architecture projects.

Examples of the coordination theory in AEC are documented in an application of the process handbook by Huang (1999). He applied the coordination model to *Computer Aided Architectural Design* (CAAD) and the impact technology has on the process. He focused in particular on the inter-organizational process of the production activities. He used the three basic dependencies, which Malone and Crowston (1990) documented as *flow*, *share* and *fit*. These types represent relationships between at least two activities with respect to the resource. A second example is provided by Schmidt and Simone (1996), who provide an outline of CSCW design based on coordination theory.

It appears reasonable that the theory applies easily to an architectural design and planning process. In a complex organization of firms and project teams, coordination is critical to deliver the product on time and on budget. Therefore, I have chosen to analyze architectural work tasks for their coordination behavior.

2.5 INFORMATION HANDLING BEHAVIOR THEORY

Having introduced the collaboration and coordination aspects in relation to technology and its applicability to the AEC industry, this section returns the focus back to the design process. Design is an information-driven process. Over the course of a design, designers handle large volumes of information. The quality of designs and the overall productivity of the design process depend heavily on the information management skills of designers. Information management is the process of capturing and organizing design information in such a manner that it can be retrieved and reused later.

2.5.1 ELEMENTS OF INFORMATION HANDLING BEHAVIOR

To understand the notion of informational behavior and some of the definitions below, assume that at any time in the design process there is an information space associated with the design framework. At the beginning, this information space may be thought of as containing design requirements. As designers work on design, they make changes to the information space either by adding information, by generating information, accessing existing information, by transforming information, or by analyzing it. The interest in information handling behavior is to gain a better understanding of the information management process. This encompasses the different activities that designers perform on information and how much information is handled by designers. The question is can the amount be measured. Different researchers have suggested methods of measurement as outlined below. Pushing this study further, are there any correlations between informational activities and the medium. If the study can document how information is used in AEC projects, potentially methods, tools and frameworks can be established to improve information management in the design process.

2.5.2 MEASURE OF INFORMATION

The activities that designers perform with information during design, which are referred to as informational activities in this study, can be grouped into three categories (Baya et al. 1992).

The first activity is *generating* an action, which adds new information to the information space from an unidentified source. This includes actions such as writing, drawing and talking. This study has not captured verbal protocols or recordings, but captured writing and drawing.

The second activity is *accessing* an action that references information within or outside the information space. This includes actions such as reading, listening and observing.

The last action is *analyzing* an action, which changes the form or representation of information. A fragment of information is considered to change if its activity changes. This includes actions such as interpret, negotiate, organize, calculate, and reason.

It is common knowledge that design information exists at various levels of abstraction through the design process. However, there is no commonly agreed categorization or understanding of these levels. Therefore, a formal definition and insight into its relationship with informational activity are needed. Baya and Leifer (1994) suggested that information also could be evaluated through the level of abstraction. This information measure is being qualitatively defined for this study. Table 4 explains Baya and Leifer's attempt to define levels of abstraction and the corresponding qualitative interpretation. The word *subject* in the Table refers to the subject of the information unit. Note that these levels are defined from the perspective of evolution of a design concept. A concept in its initial stage exists without a label (unlabelled). Once it attains a label, its level of abstraction reduces. The reduction of level of abstraction is directly related to the reduced ambiguity. The level reduces further when the concept is associated with another concept or described qualitatively, and the level of abstraction is the least (in its evolutionary life) when the concept is quantitatively specified.

Table 4.
Levels of abstraction and their interpretation (Baya and Leifer 1996, 157).

Level of abstraction	Qualitative interpretation
Unlabeled	Refer to subject of information fragment without a name, as in an idea or a new concept
Labeled	Refer to the subject of information fragment by a name, as in using a name for a new concept
Associative	When fragment contains information about relations or associations with other subjects
Qualitative	When attributes of a subject are qualitatively addressed, or when operation or motion is qualitatively described
Quantitative	When attributes of a subject are quantitatively described

2.5.3 MODELING INFORMATION HANDLING BEHAVIOR

Baya and Leifer (1996) applied this method to exactly the same workshop data as Purcell et al. (1996) during the design activity Workshop in Delft. The outcome provided a good idea of the information handling behavior, based on the verbal protocol of the designer.

Another example for information handling behavior is the VDT. The VDT at Stanford's CIFE (Center for Integrated Facilities Engineering) is software that predicts the effectiveness of a design team organization. The software tests task and flow of information in an organization (Levitt et al. 1994). The VDT assumes that managers have only a limited time and attention capacity to allocate to activities and exceptions. The model assumes an inbox of information for each actor. The actor then assigns priorities to each *message*, before processing and sending it to a different actor. The aim of this model is to calculate the total design process time of a project and to evaluate how much information can be handled. The interesting component of the VDT is that it relates the actor to their hierarchical position within the organization. It is based on the concept that each actor has a certain managerial capacity to intervene. Recent studies compared the simulation results with decisions of actual managers and the managers stated they were surprised by the accuracy of the simulation. The simulation achieved the best results for complex, but routine tasks. It is a theoretical model of the information process, but achieved a very close approximation to the industry, by using the assumption that actors can be modeled as cooperative and elements of bounded rational. The reason for including it in this review is that it deals with the information flow in a design setting and is very close to the approach taken in this dissertation research. It looks into the amount of data processed by actors during a design project.

2.6 RESEARCH METHODS

The previous sections addressed the design process, how architectural business processes information and handles interactions. The next section outlines the possible methods to collect data from an AEC project and to analyze data for the categories and characteristics described earlier.

2.6.1 TALK-ALOUD METHOD

In verbal protocol experiments, subjects talk-aloud while they are solving a problem. The audio and sometimes the video is then transcribed and analyzed. This method produces data. A major critique of this method is that it influences the subject. Researchers remind the subject to speak while working, which is distractive or at least it takes the person outside her normal routines. In addition, most of the experiments are set up in an educational environment. They do not document regular day-to-day behavior of a user. To provide an example, it would be difficult to find a business operation, where people exactly speak out what they are thinking.

An applied example can be found in Atman and Turns (2001), who documented four verbal protocol studies with over 100 engineering students as subjects (they have recently added two additional studies to their pool). In a more recent study they studied through the talk-aloud method the eight common activities of engineering design, which are problem definition, information gathering, generating alternatives, modeling, feasibility checking, evaluation, decision and communication (Adams, Turns, and Atman 2003). The reason to mention this study is that it used statistics, such as numbers of transitions and time spent, which are similar statistics that are applied in this dissertation study.

Stempfle and Badtke-Schaub (2002) used the talk-aloud method investigating the design process of three laboratory teams. Team communication was recorded and transcribed sentence-by-sentence. Utterances in the communication acts were broken down, depending on their length and the potential reason of utterance. An advantage of being able to observe a team communication is that the team must exchange information to progress. Therefore, in a team communication setting talk-aloud is not as *distracting* as it would be if only a single person were observed.

2.6.2 PROTOCOL ANALYSIS AND INTERACTION ANALYSIS

Protocol analysis is the observation of documentation of activities, whether individual or social, using a recording medium external to the process. The medium can be external observers, video or audio. Protocol analysis primarily produces texts for further study. These texts provide a description of activities and allow qualitative or further quantitative study.

Protocol analysis is also frequently applied to the talk-aloud method, which can be seen as a method of data capturing. In an experimental setting, the environmental biases are easier to control. It allows a stricter analysis (Eckersley 1998, 87):

> *"Protocol analysis is a research methodology based on the psychological theory of information processing. Intrinsic to information processing theory is the notion that thought is both the process and product of information processed by the brain. Since thought is not a directly observable activity, introspective and retrospective accounts of human thought have rightly been regarded as unreliable data for scientific enquiry."*

Previous research combined online and collaboration tools. It took place mostly in an educational setting. One example of protocol analysis was in an education environment, a class of textile students that was observed as they designed baby clothing (Lahti, Seitamaa-Hakkararinen, and Hakkararinen 2004). Groups of four students collaborated within and across the team to come up with a common design. The contributions took place during face-to-face meetings and through an online exchange tool. The entire research used 1256 design statements, posted to a database. Two independent researchers segmented and coded the data for design content, design thinking and design process phases. A bias of the research is that students were told that a major part of their grades depended on the use of the online software (Lahti, Seitamaa-Hakkararinen, and Hakkararinen 2004). Obviously, the students had not really the choice to participate or not, which might have influenced the outcome, but this concern was not part of the paper.

Two types of analyses divide protocol analysis method. The process-oriented method addresses the problem solving, its operators, plans and processes. The second type targets the content-based approach. The latter focuses on the cognitive interaction of the designer, according to Dorst and Dijkhuis (1995).

2.6.3 DESIGN OBSERVED THROUGH PROTOCOL ANALYSIS

A large number of design activity studies have observed individual designers rather than teams. Nevertheless, in the practice of architecture as a diverse discipline, teamwork is a core component to success. The number of design protocol analyses studying teams is increasing, but the majorities took place in an educational or experimental setting. Of the protocol analysis documented in literature, the most referenced and known study is the Delft Protocol Workshop. The leading design methodologists analyzed the same data through protocol analysis, applying different variables and interpretations. Cross, Christiaans, and Dorst (1996) edited the summary of all studies. The following paragraph will outline some of these studies and others, comparing the concepts and the impacts they have on current and this research.

The purpose of protocol is to establish and observe the design process and divide it into units that can be compared to each other and across projects. The following examples from the literature focused on the team rather than the individual designers, because this is also the direction of this dissertation. Since teamwork requires special attention to roles and their relationships within the team, the literature review focuses on the few examples of protocol analysis for design teams. Roles and relationships are one concrete criteria established in the design analysis conducted by Cross and others (Cross and Cross 1995; Cross, Naughton, and Walker 1981). Cross considered it important to distinguish between single designer and design team. Equally important was the role of a participant and its seniority within a particular firm. Other criteria they addressed were planning and acting, information gathering and sharing, and problem analyzing and understanding. One would assume that it is necessary to plan one's activity to fit in the environmental constraints of time and schedule, no matter if it is a team or an individual designer or planner.

In addition, Cross and Cross suggested considering any unplanned or "opportunistic" activities during the design process as well, since the design process is frequently not straightforward. Schön (1983) raised the topic earlier in his research and argued that designers constantly adjusts to new ideas and environmental influences impacting the design. The third criterion listed is undoubted essential to the design, the gathering and sharing of information that any team would have to undertake. Previous literature showed different approaches to information. The treatment of information in any protocol is therefore import to determine the process of design and who processes or generates which information (Baya and Leifer 1996). The last criterion is the problem analysis itself. It addresses the designers approach to the problem and the thinking they apply to solve the problem or generate a solution (Purcell and Gero 1998). A single designer might form his or her own meaning of a problem, but a whole teams need to come to an agreement of a shared understanding.

Many researchers have conducted research through protocol analysis. The review provides a range of example characteristics researchers examined through design protocols, but is limited to architecture and engineering design examples.

Suwa, Gero and Purcell (2000) investigated the influence of unexpected discoveries and the design goal during the design process. Their approach was to divide the design communication into individual segments. They then analyzed these segments for the correlation between unexpected discoveries and goals as interventions. The results lead to a deduction that with the development of the problem space definition the solution space also expands.

Researchers agree and recommend further development of this method to establish the validity of protocol analysis to real practice. The potential for experimental testing for research hypotheses is great, provided larger subject-samples are utilized (Eckersley 1998). Protocol analysis methodology can reveal a very exact picture of the cognitive processes while engaged in problem solving. Eckersley's study was successful in testing a potentially powerful design research methodology. He used it to confirm hypotheses and to produce evidence that designers vary significantly in the nature and amount of information processed during problem solving. An outlook in future content classifications presents Andy Dong (in print). He used terminology from linguistics, applying a latent semantic approach (LSA) to study design teams communications. The underlining assumption of LSA is that by looking at the entire range of words chosen, patterns of the choice of words can be visualized. LSA is computational linguistics tool. A similar approach, but on a simpler scale had been attempted in previous research (Winograd 1987). The use of computer speed, technology and computerized coding allows applying complex algorithms to test hypothesis as he has done. Dong used existing data from other research experiments and applied LSA to investigate the development of knowledge in designers.

2.6.4 CONTENT ANALYSIS

The main difference of content analysis is that it analyzes texts rather than producing them as protocol analysis does. The content analysis uses already existing documents, such as the original message between team members. It relies on artifacts and does not need to produce the texts, as protocol analysis does. Content analysis is a method for breaking down information expressed in text and assigning it to categories and making data quantifiable. It is a technique to create replicable and valid inferences from texts, according to Krippendorff (2004). A scientific tool used inside and outside academia and has sufficient rigor and method to be a learnable tool. It analyzes the counts of variables for each categories statistically. Neuendorf (2002) defined content analysis as: "summarizing, quantifying analysis of messages that relies on the scientific method (including attention to objectivity – intersubjectivity, a priori design, reliability, validity, generalizability, replicability, and hypothesis testing) and is not limited to the types of variables that may be measured or the context in which the messages are created or presented" (Neuendorf 2002, 10).

This scientific method attempts to be objective, although, we know that in human inquiry we cannot be perfectly objective. In content analysis, we rather strive for consistency and answer questions in the form of *do we agree that it is true*. A second step in content analysis is the a-priori definition of categories of variables; this increases the objectivity – intersubjectivity. It is very important that all the decision about the variables and their coding are made before the data observations begins, otherwise it would be inductive and violate the scientific approach. A further advantage is that it is an unobtrusive technique, which reduces the biases of the observation. Literature provides many examples where a thorough probing through the observer influenced the subjects or the position of the observer within the research. The drawback of a deductive endeavor like this is that findings might not be innovative. On the other hand, content analysis is a good tool for hypothesis testing as stated by many researchers.

Computer-supported content analysis is used, if the amount of data is very large and a manual process of coding the data for its content would not be feasible. The study uses computer support content analysis to assist the process of coding. The software used was N6, manufactured and distributed by QSR (QSR 2005). N6 is robust software, designed for large-scale studies. This software program allows easy access to data and extensive automation of clerical tasks. It was developed to allow researchers to import and export mass data to and from statistical packages. This also facilitates intercoder reliability testing and an export of findings into statistical analysis software, such as SPSS to analyze statistically the findings. A more detailed description of the computer coding is presented in section 3.5.4.

2.6.5 USABILITY ANALYSIS

Usability testing determines whether a hardware or software system meets a predetermined, quantifiable level of usability for specific types of users, carrying out specific tasks (Preece 1995, 722). The usability testing checks whether the system fulfills the user requirements. It is concerned with, in non-technical language, the friendliness of a user interface, or in technical terms, the learn-ability, throughput, flexibility, and user attitude. The learn-ability considers the time and effort required to reach a specific level of user performance on the system (Ghaoui 2003). Throughput is the accomplishments of tasks by expert users in relation to speed and amounts of errors made. Flexibility measures the extent to which the system accommodates changes in the environment. The last issues, the attitude of users towards the software is crucial, but it is difficult to measure satisfaction of users (Nielsen and Mack 1994).

The user requirements are commonly gathered with the functional requirements through observations and interviews. This is also known as the usability study and associated with an evaluation process. Preece (1995) suggested that to perform solid usability studies, a task analysis is required to determine the characteristics required of the user by the system. Overall, this research does not directly address usability. However, the literature review indicates that work tasks of the user and the user environment need to be considered, to objectively judge software.

2.7 SUMMARY

Studies on recent developments in the architecture, engineering and construction industry showed the importance to investigate information technology integration and the use of IT in architecture. They established the significance to study online collaboration tools such as WBCS. Information Technology is promising to deliver good tools for effective work environments. The effectiveness of collaborative tools needs to be judged based on the environment in which it is applied. IT needs to support the users’ needs to be successful. Therefore, an investigation of the actual use is critical.

The behavior of the participants plays a key role. Technology can be frustrating at times, the work of the team can be complex and other demands on the team member's time can be intense. If team members are not deeply committed, the best collaborative technology will not succeed. Hence, if the social hindrances can be overcome and the user accepts the application, the examples indicate the strength for future application of information technology to support collaborative efforts.

Collaboration is a very wide field and is difficult to grasp. Literature outlined the key issues collaboration and coordination. It indicated the potentials to bridge the geographical distance among team members using technology. By using tools such as WBCS, team member could achieve shared goals such as building projects. The coordination theory indicated an approach on how to measure and structure the work tasks of architects and engineers. The advantage of relating to coordination theory is that it is relates to communication and has already produced good results in the AEC industry. Hence, the main work tasks relevant for this study are the *coordination* and the *collaboration*. Yet, it did not answer what information designers use.

The two strains of design theories, design as a rational process and design as a reflection in action, provided two concepts on how designers in architecture might work. It is now up to the data analysis to show whether the rational problem solving or the reflective approach the more observed approach is. Covering both strains is important, since results are never black and white and might have shades of both. The design theory guides categories of content coding for vast amounts of data in the study, and suggests to code data for *analysis*, *evaluation* and *synthesis*.

The WBCS research is evaluating how WBCS tools are used to communicate design information. Documentation of the use of the online collaboration systems requires knowledge of the level of information within the system, such as the information handling behavior. The information handling activity has classifications of generate, *access*, and *analyze*. The second part is the how information is exchanged through these tools. Based on these findings, requirements for software could be established to enhance the information exchange in future studies or software developments.

In architecture research, it is uncommon to have these large amounts of data sets, the methodology to investigate and categorize the data is important. Compared with other methods, a computer-supported content analysis is the most appropriate for the quantitative part of the study. Other methods might need to be added.

3 METHODOLOGY

This research applied a multi-method approach to generate a clear understanding of the use of WBCS. It employed a review of previous research, analysis of data of actual building projects and qualitative practitioner interviews. This section outlines each of the steps of the methodology:

1. Select the topic and identify the research questions.
2. Review the literature.
3. Develop coding scheme for data.
4. Identify firms as industry partners and obtain approvals and permissions.
5. Collect transaction records from firms.
6. Code all records.
7. Statistically evaluate frequency of coded values and retrieve correlations.
8. Conduct interviews with practitioners.
9. Analyze interviews qualitatively.
10. Synthesize analytical results to produce conclusions.

3.1 INTRODUCTION

The foundation of the study is the analysis of real world data, analyzed by established characteristics from the literature. The literature has shown a number of examples in which small sample sizes, frequently samples from a laboratory environment were coded for content. These examples have produced good coding schemes that are further developed and applied in this research.

The main idea about this research is to use existing project data. Almost every architecture firm has this data in one form or another, but it has never been evaluated for content or any relationships within or across the data sets. Using existing data avoids any biases in the collection process or the production of these data. In most cases, the data collection began before the project was completed. Harvesting the data was an ongoing process, and took place about every week over a period of about a year. It was important to capture data in intervals, since in any design related project, data gets updated and new files replace old files. If the old files are not captured, progress is hard to evaluate. Nevertheless, all data existed prior to the collection.

It is important to understand that this research is based solely on existing data stored by the WBCS. This data were generated by architecture and engineering firms from real building projects. The datasets were generated during the planning and design phase of planning and building projects and were coded to preserve privacy. Participants were assured that no identifiable information about the project, any names and locations would appear in any documentation. This primary data was coded and translated into analyzable secondary data through content analysis. Content analysis assigned counts of categories to each message or transaction. The coding steps employed four dimensions:

1. Description of form characteristics of the message.
2. Description of substance characteristics of messages.
3. Producers of content (sender).

4. Audience of message (receiver).

The goal of the study is to identify relatively objective characteristics of messages. Hence, reliability is paramount. The study uses variables that achieve individual reliability due to the objective character of the measurement, with the exception of categorizing the message content. Under the assumption of reliable coding, the great number of units of observations increases the reliability.

Because biases are a threat to accuracy, they are avoided to the extent possible by a carefully written codebook and the discussion of measurements a priori to the study. A poorly executed codebook scheme is a threat to the reliability. The use of three coders for the content variables increased reliability. Scott's Pi reliability coefficient was used to measure the inter coder reliability.

Based on these counts, simple statistics of frequency and sequencing of tasks, information flow, and user tasks, information handling behavior and design activity can be concluded. These findings are corroborated through interviews with project participants to increase the validity of the overall conclusions. Validity is the question of whether one is measuring what one wants to measure.

By following Popper's principles of verification through falsification, the research tests the consistency of the produced reports of communication data, while comparing them with theoretical models and existing literature (Diesing 1991, part 1). This also allows one to test the proposed hypotheses. Following the principle of careful investigation, a higher likelihood of truth is achieved if all interpretations and conclusions are examined as critically as possible. The internal validity or credibility of this study and its results is equal to the degree to which the conclusion can be trusted. To increase this trust in the findings of mostly quantitative data, the findings are triangulated with theory and with qualitative discussion and project participants.

The sections below describe each of these steps in more detail.

3.2 LITERATURE REVIEW

The literature review discussed the major concepts and theories related to the research. Studies related to the current state of the AEC industry indicated a lack of research in collaboration systems applications in architecture and initiated the review.

The resources for the literature review were recent conference proceedings in the field of architecture and decision support systems. The reference lists in specific conference proceedings helped to identify prominent authors and to define the research topic further. Research monographs and journal articles became the focus of the literature review. At this point, the concepts and theories became apparent and a review of the particular theories followed. Printed journals, accessed through the Internet and the physical and electronic library provided most of the actual documents. Indexing services, like Web of science, simplified the search process to identify the network of related researchers, who referenced the original articles. This allowed to study the development and deployment of the theories in question and pointed out strengths, weaknesses and applicability of each of them.

The development of the research proposal helped to structure the literature review and indicated which topics or issues needed to be further addressed and added to the review. The outline of the literature review section of this dissertation, the development of the research methodology and the interpretations of data showed whether the literature review was complete to develop a good argument.

From the very beginning of the research, a citation database was used (Endnote) to capture each reference with an abstract. This appeared to be a very helpful tool for the duration of the research and the final writing.

3.3 DEVELOPMENT OF CODING CLASSIFICATIONS

Coordination and design related theories explained activities in collaborative work. They helped explain the match between software use and the work-organizational issues regarding the design activity during a building design project. Based upon previous research and literature these theories supported interpretation of results and provide reasoning for advantages or failures of the use of WBCS.

There are several coding schemes documented in the literature. Most of them address the design activity. They describe design activity as a rational problem solving process rather than reflection in action as indicated in the literature review above. Those studies target the designer's thinking process and describe it as a systematic problem solving process. The dissertation research employed three schemes that targeted the design activity, the work tasks of designers, and how the design information was processed. They are explained in detail below.

Before the detailed coding scheme was finalized, it had been tested with several coders and discussed with colleagues and professionals. This helped to comment on the coding, preventing gaffes and potential problems with the content analysis. The goal was to generate a set of complete and unambiguous categories and descriptions. The codebook is a description of the coding and summarizes the rules of measurements and variables.

3.3.1 INFORMATION HANDLING BEHAVIOR

The first coding system employed in the dissertation research was information handling behavior. The decision to use Baya et al.'s (1992) approach in structuring information is due to the common interest of what happens with the design information. Baya et al. attempted to develop a framework for information needs for designers and a framework to capture the requirements for tools that should support the use and reuse of information in the field of design. For this study, the information activity was of particular interest. The reasons for choosing this particular coding framework were the classifications the design activity. These classifications are similar to the classifications that need to be studied in the dissertation study to test the utilization of the WBCS. Other sub-classifications are omitted for reasons of applicability, as they would make the study more complicated and could not verify nor falsify my hypotheses. Potentially in a later study, Baya and Leifer's classification of level of abstraction could be applied to compare their data from a controlled experiment with the real world data.

Table 5.
Information handling behavior categories.

Category	Sub-category	Description
Generate	None	Provide new information, post new information
Access	None	Read information, download data, browse content
Process	None	Process information, use information to make an assertion, change and resubmit information

The difference between Baya and Leifer's (Baya et al. 1992; Baya and Leifer 1994, 1996) approach and this study is that Baya and Leifer interpreted information more as activities, where as my study focused on the actual content. Baya and Leifer's time segmentation was much shorter (several seconds) in comparison to my study, which has several minutes or hours. Hence, the level of abstraction could be easier assigned, since all information was available. This dissertation research used data of the time span of over a year. The granularity was much rougher and many of the verbal discussions or thoughts the designer might not have been captured in the WBCS. Therefore, the references required to assign the level of abstraction might not be within the immediate content and made it difficult to assign the correct level. Nevertheless, the applicability of the categories of information handling behavior was assignable and applicable to my study.

3.3.2 DESIGN ACTIVITY

I have employed a coding scheme for design activity based upon Asimow (1962). The coding for design activities took place on several levels. The content *classification* for design activity was split into the three common categories of design strategy for messages and transactions of *analysis* of the problem, the *synthesis* of a proposed solution, and the *evaluation* of a proposed solution. The next lower and finer level of each category was called *sub-category*.

Final Design Activity Coding Scheme

Based on the literature and the studies described above, this research developed a coding scheme (see Table 6) to investigate along the dimensions of design activities. It investigated the correlation between the work task and the design activity of an architectural planning and design process in relation, to sender, receiver, and communication channels.

Table 6.
Design activity categories and subcategories.

Category	Sub-category
Analysis	
	Analyze problem
	Consult problem
	Evaluate problem
	Conduct need analysis
Synthesis	
	Propose solution
	Clarify solution
	Modify solution
	Make a decision
	Declare final solution
Evaluation	
	Justify solution
	Evaluate solution
	Analyze proposed solution
	Calculate proposed solution
Others	
	None

Summarizing, Al-Qawasmi's (1999) coding scheme needed modifications, but showed good results combining channel and design activity. My study categorized most of those channels used. Regardless, the coordination effort among participants in my study was much greater due to the more complex tasks and team configuration. From Al-Qawasmi's study, the concepts of coordination effort and design activity are considered important. Therefore, the dissertation study needed to provide additional categories, which could document the coordination efforts. The data sources of the previous studies were not equipped to act as a data repository and did not needed to assign this activity. Purcell's research used the sub-classification with the difference of reducing the number of sub-levels to avoid "empty" sub-categories and ensure a reasonable frequency in each category or complete omission. In addition, the issue of external strategies or references needed to be accommodated.

3.3.3 WORK TASKS

The classification of work tasks is the third classification of content this research has employed. Work tasks distinguish between two major classifications, the coordination and the collaboration. Much of the work of architects, engineers and consultants happens in teams. They have to collaborate and coordinate to achieve the goals of design activities. While the design activities are more the cognitive activities of the participants, the work tasks are the physical work tasks. Thomas Malone outlined extensively the importance of coordination in shaping communication and organizations (Malone et al. 1999). Good judgment of the use of communication tools such as the WBCS requires knowledge of how they are used in practice. However, not all communication is purely coordination. The second category within work task was collaboration. The distinction used between both work tasks assumes that both tasks are more or less mutually exclusive. In addition, there are work tasks that do not fall under either of the categories.

Malone's process handbook describes the aspects of coordination as goals, activities, actors, resources and interdependencies (Malone and Crowston 1994). His approach showed these in terms of a tree structure, goals being the highest and interdependencies the lowest. The aim of my research was to document, which components of coordination or coordination tasks were present in the content of a message or transaction. Applying Malone's concept to architecture, as Huang (1999) did, assumes that the overall goal in an architectural design process is a successfully completed building. Based on the stated components of coordination and existing literature, several sub-categories for coding coordination were specified (Verheij and Augenbroe 2001). Table 7 shows the subcategories of coordination and collaboration used in this study. These are the *teaming efforts*, needed to establish and maintain a team, and *evaluate performances* of individual team members. This goes parallel with assigning responsibilities to team members and holding them accountable. Team members are responsible for defined sub sections of a project and it is their responsibility to ensure they accomplish the work to fulfill these responsibilities. The responsibility requires tasks to achieve a set common goal. This sub-category of *coordination of task* is a core component and directly linked to the process of assigning tasks to actors or organizing the order of activities. These tasks themselves need to be executed in an orderly fashion, an established workflow. This leads to two more sub-categories such as the *workflow* and the *coordination of the tasks*. Among these elements of coordination, other vital components are the *agreement on deadlines, dates* and the *notifications* thereof. All together, they formed the subcategories of coordination for this study.

Verheij and Augenbroe (2001) identified similar categories of work tasks, but they used a finer grain. Their categories were sometimes difficult to distinguish and not mutually exclusive. Hence, the dissertation research summarized them into coarser grain sub-categories. The main difference between their study and my study is that they completely separated the work tasks of coordination from their defined work task of teaming. It is my understanding that coordination efforts are directly related to the teaming efforts, because all team members as a whole need to aim for the common goal and cannot place priorities on their personal goals. That is the reason why I have integrated the work tasks of teaming into the work task of coordination (see Table 7).

Table 7.
Work tasks categories and subcategories.

Category	Sub-category	Description
Coordination		
	Teaming	Form a team. Keep a team, disengage a team, share evaluation records, and enforce team behavior.
	General workflow	Communicate objectives, share classifications, agree on deadline, agree on workflow
	Task assignment	Assign and delegate tasks
	Notification	Notify, remind
	Dates / times	View calendar entry / detail
	Responsibility / accountability	Assign responsibility, define accountability, assign role
Collaboration		
	Authority / permissions	Define legal rights and obligations, ask for permission, grant authority
	Assuming roles	Assume a role, agree on ground rules, define an issue
	Interaction between at least two	Invite to act, react to request, engage in an event, show intentions, reach agreement
	Approval / questions	Ask for approval / approve, ask a question, request feedback, reply, accept, answer
	Discussion / communication	Initiate discussion, carry on discussion, discontinue interaction
	Documentation	Post document, validate information
Others		
	None	None of the above

The second major category under the classification of work tasks is the collaboration effort. Collaboration has been extensively discussed in the literature review. It is the effort of working together on one product, requiring at least two people to contribute and exchange knowledge to accomplish and activity. Collaboration in my study included the discussion of issues, the documentation of results such as drawings or working documents, and the approval or disapproval of issues raised that are not related to purely coordination. The product of collaboration is in most cases an artifact or document at the end. Other elements, which are defined as collaboration, are defining legal obligations and assuming roles as discussed in (Verheij and Augenbroe 2001).

These three classifications were keys to the content analysis of the WBCS data.

3.4 POPULATION

Any empirical study must be concerned with a defined population to allow generalization of the results. The primary population of my study was architecture firms in the United States, including firms that are based in the US, but work oversees. The population was further limited to the top 500 architecture design firms according to Engineering News Record (ENR 2004). These firms had years of experience in the industry and an established practice.

This population was further limited to those firms that that are currently using Web-based project collaboration tools. The amount of the use of those WBCS tools was not known prior to the sample selection and was therefore irrelevant. At this point, no distinction was made about the level of use of WBCS versus the use of communication channels outside the WBCS.

Because of the high degree of similarity among WBCS, the type of WBCS used did not matter either. Some of the firms used commercial solutions and others used proprietary versions of WBCS.

Since the population based on the above constraints was still very broad, the WBCS research further focused on a specific project type. The projects were primarily speculative buildings, because similar buildings facilitate easier comparison among the projects. To limit the scope to a manageable degree, a limiting factor is the total duration of a building process, which might be very long and span sometimes over years. During a building life cycle, a project goes through many stages. The WBCS research targeted stages in the project life cycle between schematic design and design documentation phase.

3.4.1 CONVENIENCE SAMPLING

The actual selection of the participants was based on two factors. After a number of potential firms had been identified as potential partners, initial contact with the firms was made. The successful contacts were established through networking within the architectural industry. The next step was to explain the research idea to individuals in the firm and to get a high-level champion inside the firm to support the study. Through several iterations of discussions with the individual firms, projects were selected that fulfilled the above population criteria.

Once a project within the firm was selected, the important task of gaining the trust of the champion and, most frequently, of a senior stakeholder in the firm was required to proceed. All parties then spoke with the client of the project, since they were the owner of the actual data and had the final authority. No compensation was offered to anybody at any point during the study, which further reduced the number of available samples. Proceeding with the research study required in most cases the corporate legal department to consent to the research project and document a non-disclosure and confidentiality agreement between the involved parties and the university.

The third step was to establish connectivity to the firm's data system to view the existing data. The connection and access level depended on the individual computer and network system of the firm.

These steps of firm selection, project selection, and gaining viewing access to the actual primary data took in some cases up to one year. A more detailed description of the projects and the connectivity cannot be provided, since it would make the participating firms identifiable and violate the confidentiality agreements between the firms and the principal investigator.

This limits to some extent the level of generalizability. Drawing a perfectly representative sample is impossible, since access to this data is limited due to proprietary nature of the data. Many firms, owners and the architects are hesitant to provide unfiltered confidential information of this kind. This also applies to some software companies, which could not be included in the study, since they requested a guarantee of a positive outcome for their product. Software vendors may be afraid of losing competitive advantage by providing proprietary data, or are concerned with potential legal disputes. These are obstacles in obtaining a random sample and having access to the full target population. The only possible solution was convenience sampling. Of twelve firms invited to participate only four accepted.

3.4.2 FIRM AND PROJECT PROFILES

For the quantitative part of the research, four firms actively contributed. These architecture and engineering firms are listed among the top architecture and engineering firms in the country according to a survey by the Engineering News-Record (ENR

2004). Each firm provided their entire and unfiltered WBCS project communication database, from the preplanning through design until construction documentation stages to the research project for analysis. The firms have all in common that they each employ over 400 architects, engineers and administrative staff, who are located in multiple offices nationally and internationally. The firms were established corporations and have successfully survived through boom and recession years over the more than 40 years.

3.4.3 INSTITUTIONAL REVIEW BOARD APPROVAL

All data gathering in this research was in accordance with the Institutional Review Board to ensure confidentiality of personal data and to protect any individual involved or related to the research or any of the actual building projects (IRB 2002). Approvals were obtained for the quantitative part of the study, which is considered collection of existing data under conditions of confidentiality. The interviews or questions for the qualitative section of the study required additional approvals that were obtained prior to data collection.

3.5 SAMPLE

A strict limitation to one type of building projects is not feasible for this research, since the availability of firms and projects determines the building type to be analyzed. The higher administrators of the companies in a personal discussion with the researcher pre-selected a list of projects, from which the sample from the company was drawn. The number of samples depended on the extent of the data.

Each project team had on average 50 interdisciplinary members, who performed different roles in the project, such as client, architect, contractor, engineer and consultant (Demkin and American Institute of Architects. 2005). The exact number of team members is described in the section 4. For each project, all messages, transactions, and documents that have been posted, submitted or reviewed have been loaded into databases that were hosted within the corporations. The content from each database was then harvested either directly from the database or through different interfaces and merged into one master database, by linking the corresponding field names of each project database. Some of the data had to be filtered or converted to ensure that each field in the master database had only one type of data (numerical, text, memo, date, and time).

Data were harvested from six cases each representing a project. All cases had in common that they are high-end office or retail spaces and that the development and construction costs were above 10 million US dollars. The complexity of the projects required communication among large teams of participants over durations of several months. The data included all electronically exchanged documentation for each project. However, it did not include postal communication or communication not using the WBCS.

3.5.1 SAMPLE COLLECTION

The initial communication with firms was made through different channels, either by phone, email or through personal contacts, to establish a point of contact for the gathering of the data and the coordination process for the case studies. The way of contacting the company and the methods of data collection varied from firm to firm and from project to project. This is very common in research projects that target industry populations. A study using the same approach in architecture is described by Barrow (2000). Following the initial contact and project orientation was the legal issues of access to data prior to the data collection. The process of data harvesting took place over several month, in some cases it covered a period of over one year. The longitude of data collection ensured balancing temporary fluctuations in data and information use on the companies end.

3.5.2 ORGANIZATION OF DATA WITHIN SAMPLES

Comparing different projects represented by existing data required some kind of normalization. Each of the projects employed its own database or information structure. Comparing all the different projects with each other required one master database that can store all data. After some of the projects became available, one such database was created. The database provided certain fields that are linked with the fields of similar and comparable content of the different corporate database systems. Depending on the software used and each individual functions, certain fields had entries and others did not. The database fields and the functions are shown in Table 8. The available fields for each particular channel are marked with “x” in Table 8. The table provides an overview of the information captured in relation to the channel. The channel *documents* have no description in their original database. During an additional step, the textual content of each document is imported as plain text in the field *description* in the master database (see Note 1 in Table 8). RFIs and submittals are checked manually to enter the correct number of reference in the master database field *reference*.

Table 8.
List of general database fields and the related software channels in master database.

Channels	object ID	category	Title	author	date	time	description	reference	file type	venue	log	function
Announce	x		X	x	x		x					
Calendar	x				x	x	x			x		
Discussion	x	x	X	x	x	x	x	x				
Documents	x	x	X	x	x		1		x			
Links	x	x	X				x					
RFI	x	x	X	x	x		x	2		x		
Statistics	x			x	x	x					x	x
Submittals	x	x	X	x	x		x	2				

Note: 1: the documents have a full text instead of a description
2: on the RFI and the submittals the references are manually crosschecked

3.5.3 PREPARATION OF DATA FOR ANALYSIS

The harvesting of the data was distinguished into three different methods: straight downloads of data and direct imports into the master database; the download of reports; and individual document inspection.

During the first method, some content of a corporate database was downloaded and directly inserted into the master database or transposed through a number of queries, before it was entered into the master database. This was the most convenient case. This method was used for the statistical data, which track the users’ access and entry logs, for the document list, and for the link list.

The second path included the downloading of reports, such as the Request for Information (RFI) and submittals. These reports are available in spreadsheet format. The reports were scrubbed to eliminate unnecessary content and duplicates and were then imported through an import query into the master database.

The third way of obtaining data was the most inconvenient way. Due to some access level limitations to the main server of firms or the way project data was presented to a user, many items needed to be opened in a browser window to become accessible. The announcements, calendar entries and discussion items were then extracted as text files with line breaks, and all inserted into a Microsoft word document. Before they can be imported into the master database, several macros are applied to put the content into the correct format and save it as a comma separated file, which was then imported as a table into the database. This restructuring process was improved and automated during the progression of the study.

Of particular importance is the *description*. The field in a record *description* holds the content of every transaction or message and is a core element of this research. In the case of documents, the content of each document available was extracted from the original document in form or plain text. This was applied to any non-drawing document. The plain text was checked for spelling mistakes and then entered into the description field.

Once all data was in the master database, it was checked for spelling and unknown characters, which in particular in an international environment appeared more often than one might expect. At this point all data was in the master database and could be exported into content analysis software in a homogeneous layout.

3.5.4 COMPUTER SUPPORTED CONTENT ANALYSIS

Content analysis carries the unique position of being a primarily message centered methodology. Content analysis has three distinct capabilities. It analyzes content inherent within the text. Secondly, it addresses the property of the source of the text. The third capability is the process of analyzing a text relative to a particular context

(Krippendorff 2004). This research focused on the first two definitions, which relate to content variables and form variables. It allows analyzing the same data on different levels, if a-priori categories and sub-categories are organized in a tree structure. Communicative acts, is an example of applied content analysis. They can be analyzed either by frequency or on a macro level, such as the design steps over the whole project design period. On a micro level, the above-mentioned analysis could provide information of the different transition between the stages distinguished in the macro level.

This study in particular relies heavily upon computer-supported content analysis. At the beginning of the coding process, a tree with all a priori defined categories of coding is created or imported into system. This so called node tree can be alternated at any given time. The next step are that all messages are imported as plain texts into the system. The software imported large amounts of preformatted plain text files, which automatically were parsed into defined units of analysis. The dissertation research used sentences as units. Paragraphs were too rough and frequently contained more than one idea or action. A smaller unit of analysis would be words, but the granularity of words is too fine to be useful. Each record of a document, announcement, message, or such in the master database was then exported into a single text file, which required a unique filename. All these files were then bulk imported into N6 as documents to be coded. In a built in browser window the imported plain text files are opened, hence the message or communication displayed. Within a message each text unit, which is equivalent to a sentence, can be selected. Once a coder selects a text unit, he or she also selects a category from the tree node and can assigns a particular text unit to this category. The coder also can assign or highlight a section or word within the message and code the text unit for this particular string. This string is later linked in the node tree to a particular category. During the later automated computer coding, the computer searches all messages for this certain string or provided combination of strings and assigns it to the right category.

Parallel with this string based computer coding is the automatic *word in context* coding. A list of keywords is created by the manual coder in conjunction with a list of their synonyms. Based on the keywords and synonyms the computer codes the content variables. This includes Boolean operations and if-then rules to assign not unique keywords to the right category. If a text unit is assigned to different categories, but no category has a simple majority on this particular text unit, the computer highlights the text unit for manual coding. The manual coder has the final decision, to which category a text unit then will be assigned. Any logic or rule-based function can easily be programmed and is then automatically applied to any selection of documents fro coding or testing. The automatic coding is compared with the arbitrated result of the manual coding to increase accuracy of the coding and reliability. Based on the reliability the rules need to be checked and improved.

3.6 VARIABLES

In this research, each time a participant sent a message, confirmed a transaction, uploaded a file or edited a file, the WBCS automatically logged the access of data and recorded a log entry that includes a timestamp within the life cycle of the project. These entities have associated variables such as time, channel of transaction and roles (sender and receiver). The unit of observation in this study is the log entries generated by the software program combined with the associated message contents.

The individual characteristics of each messages were described according to Shannon and Weaver's (1998) communication model. This model provided the raw framework for the four components of every communication: *source, message, channel* and *receiver*. These four components are the focus of the entire dissertation. This analysis procedure establishes the frequency of communication among the corresponding participants of the design process, the content categories, and information flow. The study quantitatively documents what type of information is communicated from whom to whom and at what time during a project life cycle. It relates the operational tasks, which the information should achieve, to the software functions that are used to communicate the information.

The goal of every quantitative analysis is to produce counts of categories and measurements of the amounts of variables. Most variables chosen are of form content of the data provided. They can be read directly from the message or log entry, since elements are physically present and countable (Gray and Densten 1998). These variables are thought of as pertaining to message forms. The message or transaction content needs to be processed to assign it to categories. Therefore, the study differentiates between two types of variables: form and content.

3.6.1 SENDER

The first form variable is the sender of the message or the initiator of the transaction. For example, if a participant opens a file or previous message, the WBCS creates a new message, but the participant is still considered the source or sender of the information in this case. The sender categories are obviously nominal categories. Because the study tries to draw parallels across projects, the categorization of senders into individuals does not make sense. Thus, the sender categories define the actual role of the sender. The sender has three specific categories, the first being the organizational hierarchy in the own firm (see Table 9). The second table is the occupational description of the sender (see Table 10). The third category is not directly transferable across projects, only through a functional translation: the location of the sender. This location variable helps to determine if the sender is remotely located or in a central office. The definition of remote and central will be addressed in more detail in the section 5.1.

Table 9.
Organizational hierarchy of sender.

Hierarchy	2	3	4	5	6	9
Description	Director, executive	Manager, specialist	Lead planner, senior architect/ engineer	Architect, planner, engineer	Intern, analyst	Staff, Administrative personnel

Table 10.
Occupational description of sender.

Occupation	ac	ar	co	cr	em	eo
Description	Architectural consultant	Architect	Contractor, manufacturer	Client representative	MEP engineer	Other engineers
Occupation	es	fm	ob	ow	pl	re
Description	Structural/ civil engineer	Facility manager	Observer	Owner, Client	Planner, Landscape	Real estate

3.6.2 CHANNEL

The channel of communication or exchange of information is defined or limited by the software functions the WBCS provides. This is the function of the software package used to relay a particular message or through which it is delivered. The words *channel* and *function* can be used interchangeable. The categories are of nominal character. Although media richness theory suggested that the desirability of a communication medium is related to the richness of the medium (Daft and Lengel 1986; Daft, Lengel, and Trevino 1997), other researchers suggested a more subtle relationship between media and content or purpose (Rice 1992).

Table 11 shows the channels available for users. Some of the channels are only provided in particular software, as further discussed, in the software description in the data logging section.

Table 11.
Total list of channels available in WBCS observed.

Channel	Message	Drawing	Announcement	Calendar	Link
Description	Messages send through internal path	Drawings in form of DWG and PDF	General announcements for everybody	Calendar entry, add, edit, read and delete	Providing and upload a link

Channel	RFI	Submittal	Email	Document	Discussion
Description	Requesting information or answering to it	Submitting a submittal	Sending, reading, answering email	Any document submitted	Contribution to discussion board

Note: beyond the stated channels, the log entry has been captured, documenting each action and activity.

3.6.3 RECEIVER

The receiver is the person or role that receives the information or for whom the information is intended. Similar to the sender, the receiver is a nominal category and has the same three characteristics as the sender (see Tables 9 and 10). The main difference is that frequently the intended receiver is not a specific person; it might be a group of people or a certain role in the planning process. Therefore, it makes sense to use roles rather than individual participants. As discussed later, the variable receiver is relevant to prove that many messages are submitted without stating an intended receiver.

3.6.4 MESSAGE

The three form variables mentioned above rely on hard data inside the actual message that describes the form of the message transmitted. An additional variable is the time stamp that documents the time of access or submission of any document or message. These are very objective and clear measures.

The timestamp provides the date and time, when an action took place during the life cycle of a particular project. However, the common denominator is the actual date, since some of the functions or software systems did not record time with every function. The actual date is then transformed into *project weeks*. Those weeks begin with the first entry (message) of a particular project being week 1 as an interval value. Since the projects had different speeds of work progress, the project weeks had been normalized into *norm weeks*. Therefore, each project phase was distributed over 25 normalized weeks. The compression of each project is outlined below in the section on case descriptions.

The fourth variable, *message* is a content variable and not as objective. The content of the message is classified into *a priori* categories that are developed according to existing literature as outlined above.

The message data was coded into three dimensions of content as described in the section above: the *information handling behavior*, the *work task*, and the *design activity*. These three variables are of nominal values. The unit of measurement for content of a message or transaction is the sentence. Hence, each message or transaction was segmented into sentences. Within each category, they were exclusively assigned to one value to the best judgment of the coder. The test of the correlation among content categories and values was part of the study. The complete list of the categories was compiled in the *codebook*.

3.7 STATISTICAL AND AUTOMATED DATA ANALYSIS

The study of quantifiable counts of categories relies partially on statistical tests and partially on interpretation. The actual results of any of these tests are discussed in the section 5.1. Figure 3 shows a diagram of the analysis process. The quantitative usage of the software, the correlations between the sender, task, and function is documented in tabular form.

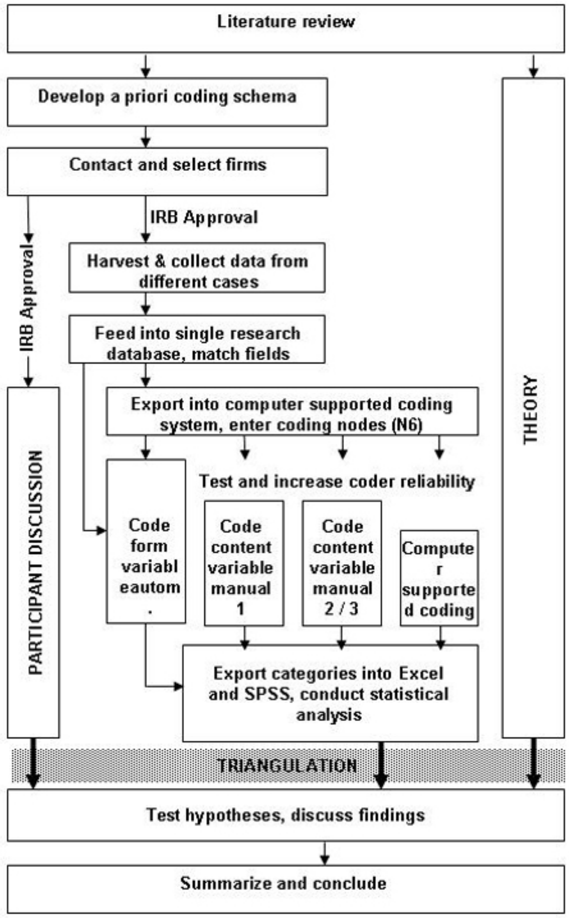

Figure 3. Flow chart of the research method.

3.7.1 CODER RELIABILITY

Coder reliability is the level of agreement among coders. Theoretically, coders should assign the same piece of information or message to the same category, but this is impossible in practice. The purpose of reliability testing is to address three main issues: the stability, the reproducibility and the accuracy. To satisfy the requirements for stability, one coder should assign the same category to the same part of the message repeatedly. Through the process of arbitration, coders gain experience during test coding and discussion of the coding. In addition, by repeating the coding tasks for several documents, coders become more skilled. The first few documents were re-coded to ensure stability with a *now* more experienced coder. This ensured intra-observer consistency.

The second step is achieving coder reliability to compare the results of the individual coders, also known as inter-coder reliability or reproducibility (see Table 12). This is related to the idea that other coders should be able to obtain the same results, given the same codebook. Reproducibility requires that the coders generating the reliable secondary data must work independently of each other while coding. From a statistical point of view, Scott's π-test was applied to the test coder reliability. The reliability test was calculated on agreement beyond chance. The Scott's reliability index π is as follows:

$$_{\text{nominal}}\alpha = (A_{\text{observed}} - A_{\text{expected}}) / (A_{\text{max}} - A_{\text{expected}}), \text{ therefore,}$$

$$\pi = (A_{\text{observed}} - P_e) / (1 - P_e)$$

with P_e being the proportion of pairs of values that are expected to match by chance. There is no overall standard regarding a minimum data reliability coefficient. Krippendorff (2004, 241) suggests three ranges of data reliability. Variables with α-values of 0.667 to 0.800 should only be used for tentative conclusions. Values below are not acceptable. The values achieved for the main categories were just above 0.800 and could be accepted (see Table 12). The level of significance for the values depended on the sample size. Since in this case the samples are larger than 100 units (Krippendorff 2004, Table 11.2), a level of significance of 0.01 was achieved.

Table 12.
Intercoder reliability for information handling behavior and work tasks.

	% - agreement	π- value beyond chance	Acceptance level	Significance level
Information handling behavior	0.89	0.82	> 0.80	0.01
Work tasks	0.93	0.85	> 0.80	0.01

The last suggested test of accuracy can only be applied if established standards outside a particular research exist (Krippendorff 2004). Since the WBCS research is a new approach of coding large data amounts from an industry environment, only vague data or preliminary findings exist, making a comparison not feasible. Once they are established, a deviation from standards can be tested. The findings of the WBCS study are compared with some similar studies in the conclusion section.

3.7.2 DESCRIPTIVE FREQUENCIES

The results of the content analysis are counts of appearances of messages within each category. At a secondary level, counts of any category in relation to any other category can be accumulated for example the normalized project week and the sender. Simple descriptive statistics can be applied to these data, such as means and medians of distributions, variances and upper and lower limits of variables. Statistics can be used to investigate potential correlations across dimensions, such as organizational hierarchy versus information handling behavior or work tasks in relation to sender, channel or receiver. The outcome of the statistical analysis is discussed in the section 5.1.

3.7.3 WITHIN AND ACROSS GROUPS

These correlations of data can be found within a project or across all projects. Due to the differences in the projects' scope and the teams, it cannot be assumed that all projects can be pooled together and analyzed as a whole. In a laboratory or educational setting, it might be possible to induce the same task with the same embedded context for different groups of similar age, professional background, and group history, so that data could be merged together, but this is impossible in a natural experiment that employs existing data. ANOVA tests were applied to test for significant differences among categories within the project itself. Following the first ANOVA test, a statistical test for significant differences within project and across the projects was applied. This determined whether all data could be pooled into one group or several groups.

3.7.4 REOCCURRING PATTERNS

The last step of the quantitative analysis addresses the order of events. The investigation into possible repetitions or reoccurrences or even linear processes of events can produce a good picture of the overall process. The data has been tested for the order of activities or internal flows of certain information, based on the occurrence and frequency of particular categories. The analysis is based on content categories primarily. The determination of whether certain orders are more prevalent than others is based on Chi^2 tests. Literature indicates that Chi^2- tests are acceptable tests for testing if a certain distribution or occurrence of events is significantly different than its distribution would be based on pure chance (Poole et al. 2000).

The common method is the Markov chain to test for sequences. It is based on the idea that an event at any point of time could be predicted based on its previous event. The number of time periods k, this particular model is trying to predict in the future is called the order of the process (Poole et al. 2000, 180). If the current time period t is used to predict the event of t+1, it is a first-order Markov process. If two periods are used, t and t-1 to predict t+1, the process is called a second-order Markov process. This model works for the analysis of event sequences, because it can generate summaries of the event dependencies. The strength of the model is that it does not need a large number of samples, as long as the samples have sufficiently large numbers of units.

The model can be view as a transition matrix, modeling the transition from one event to another over time. A model with two choices at a first-order would look like (Poole et al. 2000):

$$T = \begin{bmatrix} q_{ii} & q_{ij} \\ q_{ji} & q_{jj} \end{bmatrix}$$

It contains the elements q_{ii}, q_{ij}, q_{ji}, and q_{jj}. Where q_{ij} stands for the event i takes place at a given point in time, immediately followed by the event j. Alternative methods are a phasic analysis (Poole et al. 2000, chapter 7)) or a gamma test (Poole and Roth 1989, 1989). The phasic analysis merges events of the same type and can document a decision path for group interaction. The gamma test is based on contingency theory and the actual decision paths.

3.8 SUPPLEMENTARY PRACTITIONER INTERVIEWS

My research uses multiple methods to reduce biases and converge the results (Lincoln and Guba 1985; Yin 1994). The combination of experimental quantitative data and qualitative methodology strengthens the fit of the results (Denzin and Lincoln 1994). The interviews are complementary and only secondary to the content analysis, to cover issues not raised during the quantitative analysis and to add horizontal depth to the vertical data.

3.8.1 CORROBORATION

Through qualitative open-ended discussions with participants, an overview of the reasoning of communication that took place beyond the system's channels of transfer was gained. The advantage of adding interviews to the data set is that they provided the breadth of the study, whereas the quantitative data delivered the details. Many work tasks are conducted through WBCS, but some were still conducted outside of the system. The user involvement is essential in judging software and is of interest in assessing the WBCS.

Subsequently to collecting the data from the WBCS, interviews were conducted with practitioners, who participated in the building projects. Open-ended questions were used to add breath to the detailed data of the quantitative analysis and to cover information that was not documented by the WBCS. The interviews included questions regarding missing information and subjective interpretations on the use of the system and the users' experience. The evidence collected in the discussions indicated different facets of the communication patterns observed through the WBCS data analysis. The evidence from the interview established validity that was more external and corroborated the quantitative findings. The interviews targeted the reasons why information had been exchanged outside the system and what information.

3.8.2 SAMPLE

The selection of the interview participants was based on the previous quantitative sample selection. Some participants that were members of a project team were asked to answer a set of open-ended questions. The main criterion of sample selection was the availability of a person to answer questions. The majority of interview participants was selected based on industry contacts or were selected by the industry person, which was the point of contact for a particular research case. The size of the sample was determined by the availability and schedules of the interviewed. Team members were asked to provide personal qualitative observations and opinions. Some of the interview members were not directly involved in the documented cases of WBCS, because their projects needed to be withdrawn from the selection due to sudden client concerns.

3.8.3 INTERVIEW QUESTIONS

Most of the questions related to the project discussed during the cases observed (see Table 13). This was often subjective information and the position of the interviewed had to be considered to interpret the findings accordingly.

Three general topics were employed in the interviews. The general project communication provided an understanding how firms deal with asynchronous work in general. This allowed qualitative judgment regarding the firms experience with asynchronous and distributed team work. The second set of questions targeted the project management software experience firms had. It also asked during which stages it was employed. This allowed evaluation when *project management* software was used, since WBCS is often improperly referred to as such. The last questions were directly targeting the use and experience with WBCS. The aim was to receive participants' input on the WBCS use.

Table 13.
Questions of open-ended discussion.

Topic	Question
General project communications	
	How do you share information during asynchronous work?
Project management software	
	Which project management software do you prefer and why?
	In which stage of architecture projects do you use them most and consider them most valuable?
	What is the major hindrance that prevents architects from using WBCS?
Project specific use of WBCS	
	Who initiated the use of WBCS?
	Who pays for the software use, your firm or the client?
	Which functions of the software were the most useful to you / to the team?
	Which functions did you use outside the given software package?
	Which information did you communicate outside the online-software?
	Where do you encounter problems and limitations with the software?

3.9 SUMMARY

The research method of this dissertation could be summarized in ten steps: The first step was the identification of the research topic, based on current publications and recent conference topics. The next step was the literature review of related topics to establish a baseline of comparison and to identify the important theories, such as design theory, coordination theory and information handling theory. This step provided the first lag of the triangulation for this study. Based upon the literature review and the theories the third step were the establishing of the coding scheme and the coding classifications for the variables. These classifications were used in the content analysis.

The forth step were the identification of firms as industry partners and providers of the raw data. The raw data was original building project data. Once the firms agreed to share their information, the next step was to harvest their information over a period of about year per project. This data was then coded through computer-supported content analysis, including manual coding, coder reliability testing, arbitration and automated computer coding. This transformed the original data into countable secondary data. The next step were the statistical analysis of the secondary data to identify any patterns. This included tests for any significance of relationships or reoccurring patterns, creating the second lag of the triangulation for this research.

Following the quantitative section was a practitioner interview phase that added horizontal information. This horizontal and qualitative user information added to the large vertical data set and created the last lag for the triangulation.

In the last step the results of all three lags were triangulated and produced the final synthesis. The interpretation of both analyses took place in the light of theoretical models. This produced conclusions and allowed making recommendations on improving the processes and the software.

4 QUANTIFIED EVIDENCE FROM TRANSACTION LOGS

The following section explains in-depth the exploratory stage of the WBCS study and provides an overview of the projects studied and the software used for each particular project. The projects have some differences in content and scope. This section provides descriptive statistics and simple comparison among the projects data sets. The description is to the best extent possible without violating the confidentiality and non-disclosure agreement between the principle investigator and the firms.

4.1 INTRODUCTION

Six projects obtained from design firms have been included in this study. All projects were above 10 million US dollar in building cost; they were all commercial building types combining office space and retail spaces. All were designed for prestigious locations and had a high visibility within their respective communities. Locations in four countries and six cities are represented. Sites included suburban and inner city locations. The six projects produced about 30,000 transactions (see Table 14).Each project is recognized by an abbreviation, which is a randomly generated three digit strings, ensuring the confidentiality of the firms and its clients. Table 15 shows the actual amounts of documents and transaction per case.

Table 14.
List of cases observed.

Case	Index	# firms	# team members	Active members	Locations	Duration [weeks]	Start date	End date	System used
1	AWM	13	172	44	32	56	Dec 03	Jan 05	2
2	GCD	6	55	22	2	74	Feb 03	Jul 04	2
3	BRA	8	46	14	10[1]	48	Oct 02	Sep 03	1
4	EAF	10	151	67	29	65	Aug 03	Nov 04	1
5	IBG	7	15	10[2]	3	4[3]	Jul 03	Aug 03	3
6	HSU	6	28	20	8	49	Dec 03	Nov 04	3
	total	50	467	177	84	296			
	average	8	78	30	14	49			

Note: 1. the list of locations of the participants was not complete, 10 is an estimated number.
2. the system did not allow distinguishing between active and passive participants, 10 is an estimate.
3. the data available was only from a highly active period of 4 weeks, because previous data was inaccessible.

Table 15.
Amount of documents and transactions per case study used.

Case	Index	Design stages covered	Documents	Transactions
1	AWM	Preliminary design	922	19416
2	GCD	Design documentation	245	962
3	BRA	Preliminary and master planning	148	148
4	EAF	Feasibility and preliminary design	303	3292
5	IBG	Construction documentation and admin.	0	1405
6	HSU	Construction documentation and admin.	1466	1467
	total		3084	26690
	average		617	4448

Note: 1. this significantly higher number of transactions has been considered during the research. To avoid distortion of the overall results, the cases where only combined, if there were no statistical differences.

4.2 CASE DESCRIPTION

4.2.1 CASE 1 - AWM

Case one spanned several buildings of a telecommunication corporation. The project addressed the restructuring of office space and the extensions thereof. Data was collected from the pre-planning and facilities planning stages. Observations were made over a 56-week period. Much consideration was given to the future use and adaptation of space for future work forces. The WBCS used on this project was system 2, as described in section 4.3.

The project team consisted of representatives of 13 firms and included real estate brokers, architects, planners, architectural consultants, engineers and owner representatives. This large team consisted of 172 team members over the duration of the project. However, not all team members were “on board” at the same time. Table 14 shows that 44 different project participants contributed documents and messages using WBCS. These participants are referred to as active participants. However, the majority of team members primarily read and reviewed documents (passive participants). Frequently, these passive team members contributed during face-to-face meetings, and their contributions were submitted by one of the active team members.

One of the reasons for using a WBCS was the geographic distance among those team members, who were located in 32 cities around the globe.

The documents available for this research were announcements, schedule related entries and calendar entries, threaded discussion items, and other documents submitted. The documents and discussions included meeting minutes and agendas, reports, presentations, financial documents and spreadsheets. There were 922 documents stored in the system that have been studied in this research. Documents were submitted in various forms, such as Microsoft Word, Excel, PowerPoint, reports, and others, but were transformed into plain text, before they were feed into the master database and analyzed for their content. Overall, there were 19,416 transactions recorded during the one year of observation period. This is equal to approximately 75 transactions per standard workday.

4.2.2 CASE 2 - GCD

The GCD project was sited in the metropolitan core of a major city. It challenged the architects and planners with tasks from the master planning phase to the design stage for a series of retail and commercial office buildings, including the revitalization of a major *landmark* in the city. The project was of high visibility for the city. The duration of the observation was 74 weeks, but only the first 60 weeks were used for the analysis. The period at the end of the observation was characterized by many delays and only low activity among the participants.

This team was mostly located in the same major city. The high level of public attention of the project and importance of the city led to a requirement that each of the six participating firms already had an office at the project location. The team consisted of 55 members, many of whom were specialists that used the online discussion board extensively, even though physical meetings were relatively easy to establish due to the proximity of all team members. The strong active participation can be deduced from Table 15, which shows that 25% of all transactions result in an actual document (# of documents divided by # of transactions).

Transactions included threaded discussion entries, announcements, the use of links to external documents, meeting minutes, and word processing documents, spreadsheets, and an online survey.

4.2.3 CASE 3 - BRA

The BRA case was a corporate headquarters building for a major US insurance company. Observations were conducted from the master planning phase through the preliminary design phase. The duration of the observations was 48 weeks.

The project team consisted of several architecture firms, planners, and the client representatives themselves. The master plan project was conducted by an international architecture firm in cooperation with a local architect. This is a very typical approach for architecture projects. The 46 participants from the eight firms were located in probably 10 different locations. The exact number is not available, due to minor omissions in the original data entry that was provided through the system.

Table 15 indicates that primarily documents were posted on the WBCS, which were available for the analyzis. One reason that the depth and the variety of data produced by this case are so limited is that a new system was used. The online collaboration tool was developed as in-house software. It provided only a limited variety of functions and channels. Later versions of the software were much more sophisticated and allowed richer data to be transferred. At the early stage, this software provided a shared document repository and scheduling capabilities, such as online project calendar.

4.2.4 CASE 4 - EAF

Similar to case 3, the EAF case used a very early version of WBCS. The project was a conceptual planning project based on information of existing office buildings and the potential to improve the use of them. The project could be categorized as a master planning and facilities planning project. At the beginning of the data harvesting process for this research project, this project was already well on its way. The total duration of the project was 65 weeks. Nevertheless, there were long periods of inactivity. For this research efforts the activities have been compressed into 25 weeks. This compression was reasonable, because there was no obvious disconnect during the inactive phases and no changes in the staffing of the project.

The team was large and complex. Ten firms with 151 team members were involved in the EAF project. These participants were distributed in 29 locations around the world. A closer look at posting times, when each document was submitted or any transaction took place revealed that occasionally someone was working on this project in each of the 24 sequential hours. This makes this case particularly interesting, since asynchronous communication was a mandate for success. Hence, it might not be surprising that this team has an above average of 44 percent of active contributions into the WBCS, compared to all other projects with 38 percent. A more detailed description regarding the active versus passive participation is provided in the next section.

The team relied heavily on the document repository function of the software and the threaded discussion board. Neither the calendar function nor the project *bulletin* board was strongly used.

4.2.5 CASE 5 - IBG

Similarly to the other projects, IBG involved the design of a commercial office space in a high-rise building that provides retail floors in the lower levels. In contrast to the previously described cases, this case investigates the use of WBCS during the design development, the design documentation, and the construction administration phases. Unfortunately, there was no option to harvest directly data as an ongoing process. This was due to liability issues and due to financial restrictions in the use of the software. Therefore, only a 4-week snapshot of data and transactions was available for the study. The pricing of the WBCS increased with the number data storage and the number of participants, who needed access to it (seat license). The firm providing the data had to pay for the license of the investigator needed.

Regardless, the snapshot provided a great spectrum of data generated from 1,405 transactions. Seven firms were involved in the project. Team members included clients, future tenants, architects, engineers, construction and project managers. Most of the 15 team members were active users of the system. The exact number of active versus passive users cannot be determined objectively, because the software used, system 3, did not capture this information. It can be safely assumed based on the document content submitted that about two thirds of the team actively contributed. The documents included drawings, office documents and email messages. Additionally, many images and reports were submitted.

4.2.6 CASE 6 - HSU

The last project observed, HSU, covered almost a one-year period. The case documented 49 weeks of observed transactions from the design development until construction administration phases of an urban high-end retail building. The building project was an addition to an existing facility and included the renovation of the old section of the building.

The six-firm team was disbursed over eight locations, as outlined in Table 14. Participants included the architect, structural, mechanical and electrical engineers, the owner representative and the general contractor. This team had the highest amount of active participants with 71% activity.

Although the team utilized a commercial WBCS, with many features, they used it largely as document repository and utilized mainly the RFI function and the submittal channel. Both channels are highly associated and linked with drawing documents, reports and discussion items. Overall, there were 1,467 active documents logged.

Although this system included a built-in email function, it was not used, because all members used their own corporate exchange server, which was not integrated with the WBCS functions. This is understandable since most team members in the AEC industry are assigned to more than one project at a time. A checking of various email accounts is not suitable. Since verbal communication and face-to-face could not be captured over a long period, written meeting agendas and meeting notes were provided by the firms.

4.3 SOFTWARE DESCRIPTION

The entire primary data set has been generated from logs produced by three WBCS that are typical of those available on the AEC market. The systems' common functions are file repository; calendar functions and a team directory that lists all project participants with their names, company names, phone numbers and link to their emails. All participants used their corporate email accounts rather than email functionality built-in to the online system. The only exception is the case 5, where in a few cases participants used the built-in function. Another common function is a project message board, which provides information regarding the overall project on a very general level. This message board or announcement site is usually the first page displayed once a user opens the portal.

4.3.1 GENERAL SYSTEMS FUNCTIONALITY

The core concept of Internet based collaboration systems is that they provide instant access for project participants, out on the site or in the office. They can retrieve knowledge or data any time of the day and the week and can contact other team members that are required for a specific task.

Log Entry

All systems used for the six cases are accessible through the Internet and can be accessed outside and inside the corporate firewalls. Therefore, users are provided with individual logins and passwords and are authenticated through standard protocols. The online system communicates based on a secure shell connection, such as https. The system recorded each action in a log file, when members were logged on and authenticated. All participants can have a different assigned access level with specified privileges such as administer, change, write, edit or view. These privileges are defined on a function, folder, or file level. However, none of the firms had limited members' privileges, with the exception of the project client's access rights in cases 1 and 4.

Team Directory

The project team directory holds addresses and telephone numbers. This reduces the burden and loss of time caused by extensive searches for people's information. The information system facilitates the every day business process, but an information system can only be efficient, if all users are aware of the necessity that their entries need to remain current and constantly updated (shared responsibility and common purpose). The directory is one of the most commonly used applications in these case studies and in today's business environment. This feature is used synchronously to retrieve someone's telephone number and asynchronously for emails, job responsibilities or to obtain marginal background information about a team member. The directory is a vital part to establish a mutual understanding of the team and its team members (Lorenz, Mauksch, and Gawinsky 1999). Although, it often duplicates information many corporations and architecture firms have already stored internally on their Microsoft exchange servers. However, once team members from other firms get involved, they might not be listed in the in-house list nor have access to other firms contact lists.

Calendar Function

The second function is the calendar function. It is one of the major categories of coordination technologies. It is often referred to as one technology, but it compromises actually two different functionalities. Calendaring includes the placement and manipulation of data on a calendar. This sounds very trivial, but in reality scheduling involves the communication and negotiation between calendars for such placement (Munkvold 2003). It becomes a critical point of coordination towards a common goal. It also must obtain the critical mass of users to become successful collaborative technology. This can be enhanced by the ease of use of the function.

Document Repository

The document repository is common to all systems and is at the core of any online collaboration tool in AEC. It is a replacement of insecure FTP sites that did not have easily controllable levels of access. These document repositories are structured through a database system that is controlling each entry, access and edit on the documents. The document repositories are shared information spaces that provide a searchable knowledge repository. That makes it easier to react to arising issues in the design process. The repository provides effective collaboration to any Web-based project team. A team member has access to the latest data, 24 hours a day, 7 days a week from the office, from a job site, or from a client or consultant site. The effectiveness is dependent upon keeping the shared electronic documents updated, which does not always happen.

Occasionally one file was observed to be submitted several times. Participants might have not noticed the existence of the previous file or did not use the search function to look for it. Some of the problems with the versioning of files and the ownership are addressed differently by the individual systems. Each of the functions described above has slight variations within each system described below.

4.3.2 SYSTEM 1 – EARLY IN-HOUSE

The first system is a proprietary system developed by an architecture and engineering firm and hosted at an off-site location. During the course of data collection, the product had been continuously developed and improved through an increase of features and functions. The usability was improved through a simplification of an advanced user interface.

In addition to the above list of generic functions, system 1 had a simple discussion board. Discussion boards allow members to post messages online. Others can then decide to respond to a particular posted message and append their comment or can post a new topic. Discussion boards can be used synchronously or asynchronously. The version provided in the system was a treaded discussion board, meaning that messages are organized in a tree structure, depending where the author of a message or response posts this message. Cases 3 and 4 made use of this early system (see Table 16), which was developed parallel with the actual planning process for the building projects and its demands. It was also used for other projects in the same firms that are not part of this dissertation research.

Table 16.
Functions of systems and its use per case.

		System 1		System 2		System 3	
	Channel	Case 3	Case 4	Case 1	Case 2	Case 5	Case 6
Functions	abbr.	BRA	EAF	AWM	GCD	IBG	HSU
Announcement	ano	no	yes	yes	yes	No	no
Calendar details	cal	no	yes	yes	yes	not used[1]	not used
Calendar outline	cal	yes	yes	yes	yes	not used	not used
Discussion board	dis	no	yes	yes	yes	No	no
Document repository	doc	yes	yes	yes	yes	Yes	yes
Email function	ema	no	no	no	no	Yes	not used
Link farm	lin	no	no	no	yes	No	no
Log entry	sta	n/a[2]	yes	yes	yes	Yes	n/a
RFI - feature	rfi	no	no	no	no	not used	yes
Submittal procedures	sub	no	no	no	no	not used	yes
Team directory	mem	yes	yes	yes	yes	Yes	yes

Notes: 1. Not used: stands for the software provided the feature, the research would have captured a use of the feature, but nobody actually used it.
2. It is not applicable. Although the software had the feature, the research mechanics could not capture this information.

4.3.3 SYSTEM 2 – ADVANCED IN-HOUSE

The second system is also a proprietary system, comparable to system 1. It was developed internally by an architecture firm, which acted as prime contact for the client. Compared with the previous system it provides a better threaded discussion board and a link farm to outside resources, as documented in Table 16. The link list is an interesting approach, since in the AEC industry the referencing of details and manufacturer specifications is increasingly important. The link connects to a structured list of links to resources, publications and documents, which are, hosted any where on the web and are publicly accessible. Recent developments in this area are CAD programs and parametric modeling, which link door or window schedules to manufacturer Websites for more details for example. This is also consistent with development of aecXML, which allows referencing external data to the main data or building information (IAI 2004). This is motivated by increasingly more sophisticated details and materials available to architects (Johnson and Laepple 2003). These link farms allow to reference external documents and Websites. They are organized in topics. The link farms provide short descriptions for each link. These links provide a better connection to pieces of information through vertical integration.

4.3.4 SYSTEM 3 – OFF-THE-SHELF

The third system is a commercially available software package. It is used mainly during the construction documentation and administration phase, according to interviews conducted with several participants. Cases 5 and 6 used this software, with comparable software versions. One difference to the in-house versions is that this system has an advanced versioning and version tracking capability built into the software for the document repository. This is useful to track changes in the design and during the construction process. Architects and contractors stated during the interview that it introduces a liability issue by keeping copies of *everything*. The fear of being sued and the expected standard of care are demanding form the industry and its participants. Nevertheless, a closer investigation reveals that in neither of the two cases were previous versions of documents actually used or viewed during the period of observation. When usage fees for online collaboration tools are tied to storage space used, previous documents are removed very soon from the server and stored elsewhere.

The major additional channels system 3 provided are a RFI (Request for Information) and Submittal functions with version control of all digital documents as indicated in Table 16. This allows participants to submit a question, possibly associated with a document or drawing and then direct to a specific receiver. The receiver can then approve, disapprove, or even reroute the request to a more appropriate personal, as he considers it appropriate. This system provided a built-in routing function, where participants send requests to particular receivers. Notification of a posting or submittal could be send through the built-in email function. In reality, the notification was typically sent through the corporate email server. The target mode of collaboration for this software is clearly asynchronous. None of the functions required the participants to be working on the system at the same time. The question of co-location or distributed teams is independent to the software; it can be used for both cases.

The project related information stored on the WBCS in cases 5 and 6 was important to team members of other firms, outside the architect's firewalls. Beyond the WBCS, each individual firm used their own in-house data servers for a considerable amount of information, according to the interviews. This information was not accessible for project members outside a particular firm. It can be concluded that the system was used to facilitate the dispersed team rather than co-located team members.

4.3.5 OTHER SYSTEMS - INACCESSIBLE

In addition to the systems above, I tried to obtain other software samples with actual data to increase the generalizability of the study. However, other commercial off-the-shelf software was not possible to integrate because the software providers were not willing to provide free software without guarantee of a direct profit.

4.4 SUMMARY

The observation and collection phase of the research produced a rich and extensive data set from the WBCS logs and document repositories. Table 17 provides and overview of counts of messages per channel.

Table 17.
Number of messages per channel captured.

Channels	Counts of messages per channel
Announcements	126
Calendar entries	835
Discussion messages	97
Documents: drawings	15
Documents: text only	149
Documents: reports	257
Documents: spreadsheets	179
Links on link farm	24
Requests for information	400
Submittals	1002

Note: 1. the submittals contain drawings and text combined in each message
2. each message has an average of about 45 text units.

One of the major findings through visual observation was that many functions of a system are not used at all or not to their full capability. This is consistent with critique from users that learning or changing common processes as long as the old ones suffice the job tasks is very difficult or not convincing.

5 INTERPRETATIONS

The research is based on three methods, the first being a thorough literature review to establish a baseline of comparison and to identify hypothesis to be tested. The second is a quantitative analysis of existing building project data, which had been produced during project communication and documentation and information. The data, which is described in the previous section, has been subjected to content analysis. During the content analysis, various categories and subcategories are assigned to the units of observations. The relations among content categories, senders, channels and receivers are used to test various hypotheses. Information from practitioner discussions and interviews has been collected and is used to supplement the content analysis with respect to validity. Based on the results of the hypotheses testing and the corroborating interviews, the findings are summarized in a final section of this section.

5.1 HYPOTHESIS TESTING

Many publications and trade magazines document experience and traditional knowledge in the AEC industry. Researchers and designers have various assumptions regarding the design process and the daily work operations in architecture and engineering. The majority of studies in this area are based on controlled laboratory environments or generalizations from practical experience.

This study differentiates itself by relying upon data obtained from natural experiments and testing it against established theories or *common knowledge*. The following sections test several hypotheses with qualitative and quantitative methods.

5.1.1 DIFFERENCES IN WORK TASKS

Collaborative design is a process of actively communicating and working together to jointly establish design goals, search through design problem spaces, determine design constraints, and construct a design solution. The complexity of the problem has proved resistant to achievement of a consensus description. The question remains what tasks do designers need to complete to be successful? Can design be broken into contributing tasks or is it impossible to systematize?

Since each project was studied for a different duration, the total time for each case has been subdivided into 25 equal *time units* to allow comparison. These weeks are called *normalized weeks*. In addition, the six cases are split into two groups, the first group is projects during the feasibility and preliminary design. The cases AWM, BRA, and EAF are in the fisrt group. The second group, including cases GCD, IBG and HSU, was observed during the design documentation and construction documentation.

Work Task Changes over Time

If design can be separated into sequential steps as a rational process, as outlined in the models in Figure 2 and 3, then the steps should exhibit different characteristics that might be distinguishable in the usage of WBCS. In the previous section, Table 7 lists the various tasks the individual must complete during the design and planning process according to theory. Based on the data provided in the three cases that are focused upon design, Figure 4 provides an overview of a change between coordination and collaboration tasks. Conclusions can be drawn on the general ratio changes of coordination below the line with the ratio of collaboration above the line. Coordination and collaboration are not always mutually exclusive, but the error is reduced over the large number of units of observations. The trend line shows that the ratio changes over time.

Figure 4 shows the scatter plot of the three cases during the design phase, AWM, BRA, and EAF. A log linear regression produces a trend line based on the weekly ratio for the duration of the project stage.

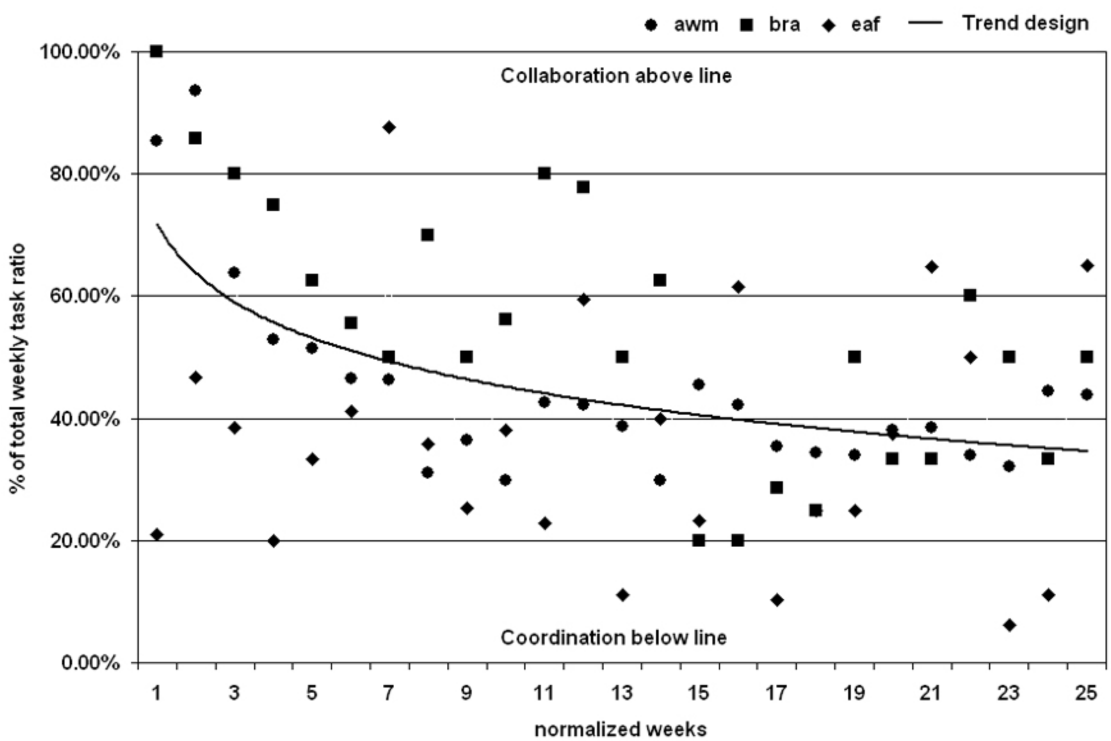

Figure 4. Changes in ratio between coordination and collaboration. The dots in the scatter plot show the weekly ratio for each project. The percentage above the line or the dot is the amount of collaboration, below the line is the coordination.

Work Task Relation to Project Stage

Figure 5 shows the averages ratio of coordination and collaboration each normalized week and their trend lines for the group pf cases focused on design and the group of cases focused on documentation. The figure differentiates between cases that were oriented toward the planning and design stage versus cases focused upon construction documentation and administration. Figure 5 shows that the ratio changes from the early design phases and the pre planning stages. Figure 6 summarizes the total ratio per group. The figure suggests that the most collaboration takes place during the design phase, while in documentation the individual team members mostly coordinate their work, rather than collaborate.

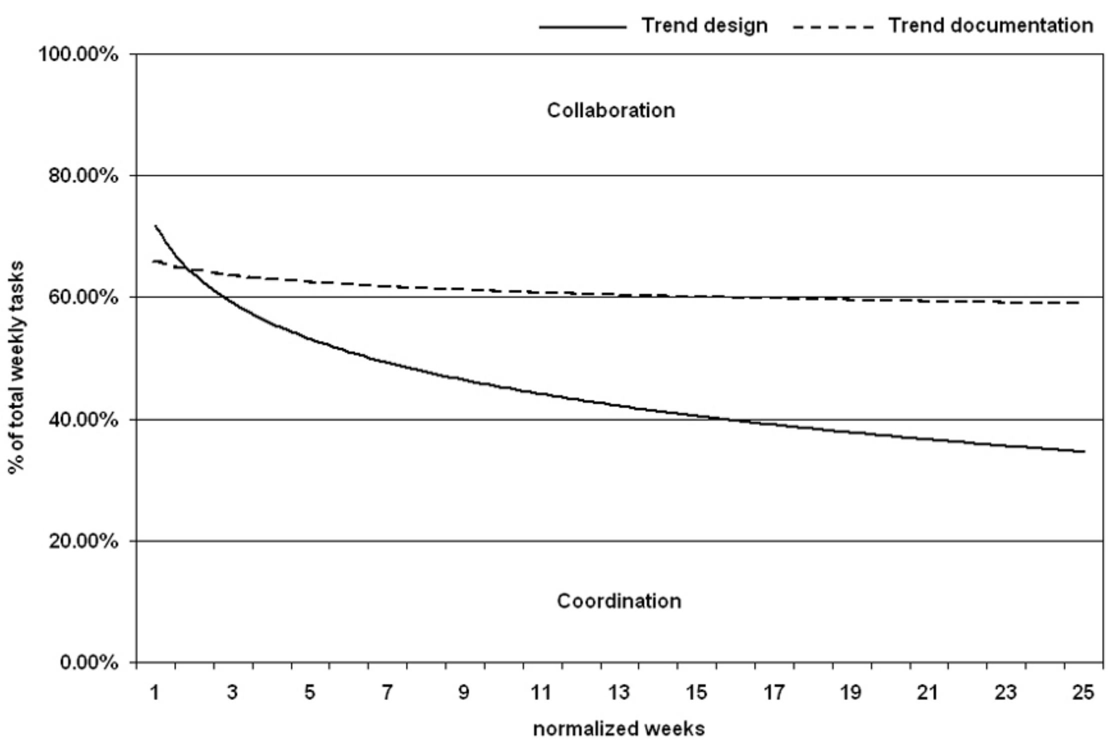

Figure 5. Ratio between coordination and collaboration in the design stage.

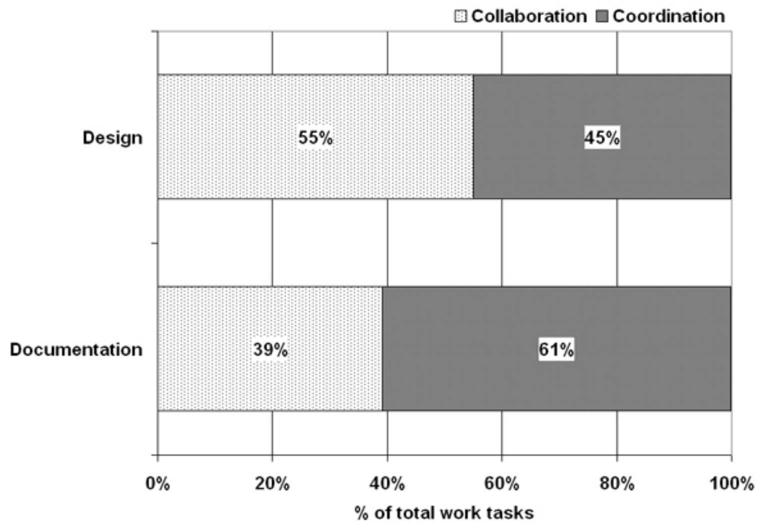

Figure 6. Ratio between coordination and collaboration in the construction documentation.

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 (see Figure 6 and 7). However, the progression is more apparent in the design phase than the documentation stage. The appearance of flurries of message of one category type within a phase characterized by another category type needs still more study. Details are in particular important, since the number of cases is small and averages only have guiding character rather than definite answers. Perhaps patterns that allow distinctions of sub-phases will emerge from analysis that is more detailed.

The figures illustrate a qualitative difference between the two categories of cases. In cases that focused upon planning and design, illustrated in Figure 6, the proportion of coordination activities decreased dramatically over time. It started out at about 70% and then declined to below 40% on average. In the cases focused upon construction documentation (see Figure 6), the mix between coordination and collaboration stayed more constant for the duration of the project, 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. The involvement of new participants and larger more diverse teams probably requires a greater effort of coordination prior to collaboration.

This view of the design process is supported further in the categorization of design collaboration identified by Maher, Cicognani, and Simoff (1998) in their experiment in collaborative design. They note that the *exclusive collaboration* model is the most effective and the one in which they observed most productive results (Kvan 2000). The exclusive model assumes that team members frequently work by themselves and only share and exchange information, if the project requires it. Otherwise, collaboration becomes too time consuming (Schrage 1990).

The balance between coordination and collaboration is a focus point of many teams. Organizing the group process and selecting the right type of collaboration is a major task in design collaboration. Stempfle and Badtke-Schaub (2002) showed in their study that during face-to-face communications in groups, two-thirds of interactions are content related and one-third of the group communications targets the organizational process of the group. The evidence from my study shows a different ratio. The amount coordination efforts was higher, during the design phase about 40% and during the documentation 60%. This could be because the participants were mostly not co-located and had to arrange for their “meeting” before they coul exchange and collaborate.

Types of Work Tasks

A more detailed observation of the sub-categories of work tasks, related to the messages, shows that the *general workflow* accounts for the largest amount of work tasks (see Table 18). The average of all other coordination tasks accounts for about 3 to 7% of work tasks. The average is used as a rough guidance for interpretation, since the projects are statistically different and cannot be merged without caution. The distinction between general workflow and the coordination of tasks is not always mutually exclusive; hence, some of the text units could be in both sub-categories. An explanation for these large amounts of workflow related exchange, could be that many messages and documents are simply uploaded or submitted to the system, without a specified receiver. This information needs then be managed through coordination tasks, since no receivers might not know of its existence. In the past, a team member would have sent a file to another team member and he or she would have known what to do with it. The WBCS are frequently used as a data repository, requiring an additional message to somebody to follow up on the document. An automated routing built into the system and used by the participants might reduce the amount of messages exchanged. However, since the WBCS has no traditional benchmark to be compared with, more objective judgments are not possible at this point.

Table 18.
Ratios of sub-categories of task content in messages.

	AWM	GCD	EAF	HSU	Case avg.
Coordination					
Teaming	0.07	0.13	0.01	0.01	0.07
General workflow	0.28	0.02	0.20	0.20	0.21
Coordination of tasks	0.07	0.02	0.02	0.02	0.04
Notifications	0.03	0.07	0.00	0.00	0.04
Dates, times, schedules	0.09	0.08	0.04	0.04	0.07
Responsibility, accountability	0.07	0.00	0.00	0.00	0.03
Collaboration					
Assume roles	0.01	0.00	0.04	0.04	0.01
Interact between at least two	0.12	0.50	0.02	0.02	0.18
Approve or question	0.07	0.02	0.21	0.21	0.09
Discuss or communicate	0.08	0.04	0.07	0.07	0.07
Document	0.12	0.12	0.41	0.41	0.19

Note: 1. the row for authority is omitted, since it had no recorded tasks.
2. the table is based on four cases, since they these cases had large amounts of documents and messages that were long enough to be analyzed on a sub-category level.

The second largest amount of tasks related content in messages is a collaboration task: the *documentation.* This strengthens the assumption that the system is frequently used as a document repository. The third frequent task category lies also within the collaboration sector, the *interaction between at least two team members*. The next sub-categories are *approvals* and general *discussions* among team members. With more than half of all task content in the messages across all project stages being related to collaboration, it can be assumed that WBCS are used as a collaboration tools. A more detailed investigation into the sub-categories reveals, for which tasks the team members are using the WBCS.

5.1.2 CHANGE IN INFORMATION HANDLING BEHAVIOR

Baya and Leifer described a framework for analyzing the information handling behavior of designers (Baya and Leifer 1996, 1994). The information handling behavior distinguishes between information generation, information access and information process. Their approach targeted in particular the rate at which design information is handled and suggested a correlation between the rate and the information processing abilities of designers from a cognitive viewpoint. I have investigated how the information handling behavior changes and if it changes depending on the project state. This could provide insights for developing information management tools needed to support conceptual design.

A comparison between different design stages is apparent from an investigation of the type of information handling behavior. Figures 8 and 9 show the proportion of activities for each normalized time unit as grouped into classifications of “access”, “generate”, and “process.”

Eighty percent of the transactions is only accessing or reading information. They do not contribute new information to the information pool across all cases. Figure 7 shows that 90% of the activities in the early stages are *accessing*, reading and assimilation of information. In construction documentation, only 50% of activities were for accessing information, as illustrated in Figure 8. *Generating* new information and processing data account for the remainder of transactions or messages.

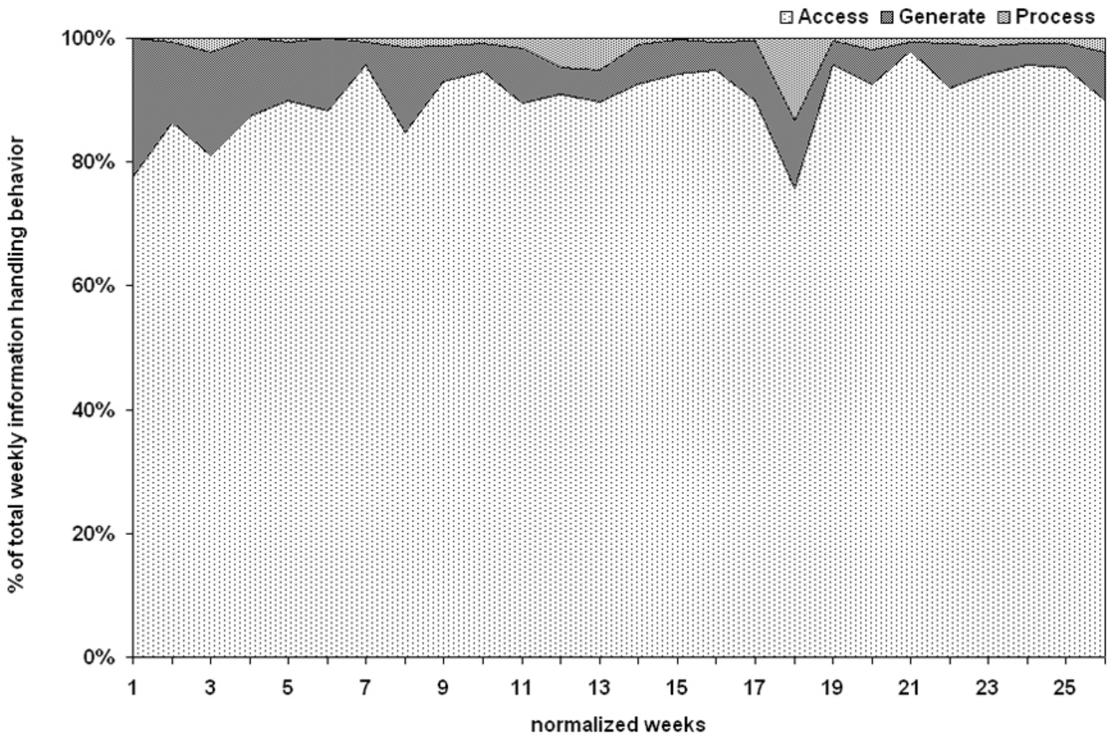

Figure 7. Information handling changes during the planning and design development stage.

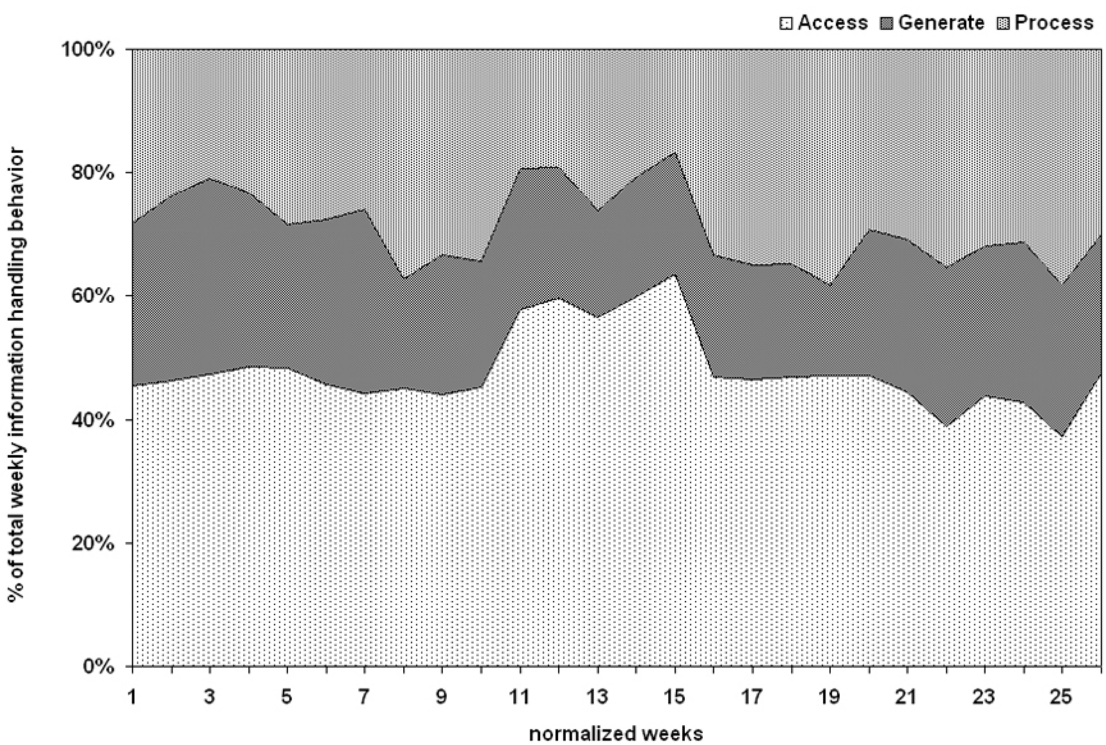

Figure 8. Information handling changes during the construction documentation stage.

With the progression of the projects, information handling behavior type change from pure messages, review of background information, and negotiations to more output and production-oriented information (see Figure 9). The cases show that the main production of new issues or documents, such as drawings and detailed descriptions of the building, are accomplished at the later phases. In addition, the involvement of the owners is lower towards the later stages of the project.

An actual tracking of the change in information type over the entire project life cycle would require observation from the initiation of a project to its completion and potentially the operation. However, not all cases have gone through all stages of design, construction and operation. Future studies could collect additional information that may allow a more complete picture of which information is used at each stage.

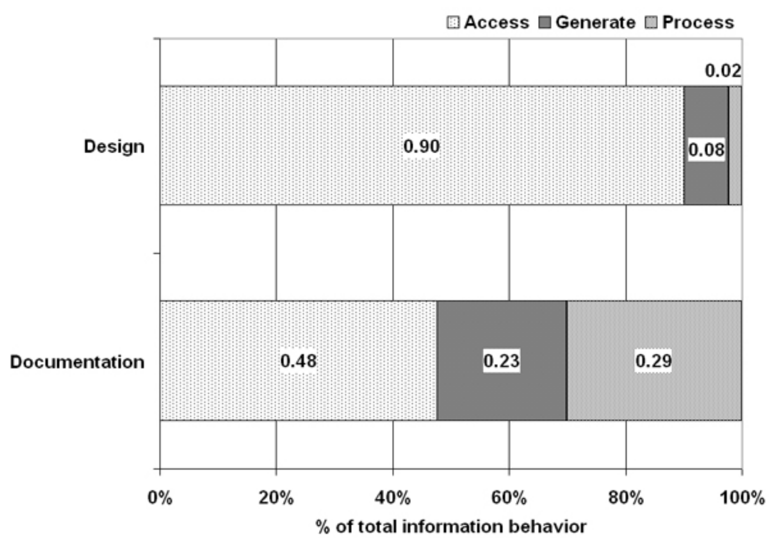

Figure 9. Information handling behavior during design development stage versus construction documentation (Laepple et al. 2005).

The results in Figure 9 show similarities to Baya's findings for the documentation phase (Baya and Leifer 1994, 158). In his 1994 study the percentages were similar to the ones found in my research (Generate = 54%, Access = 23%, and Process = 23%). The design phase in my observations is significantly different from Baya's study. There is no obvious explanation for why many participants were reading information, but did not contribute new items. They used the WBCS as a good resource but not to share their knowledge. One minor assumption for the high ratio of access information versus process and generate information could be that the designer did spend much time with one solution rather proposed different solutions. A particular solution might be posted prematurely and remains unrevised. This would be coherent with research in cognitive psychology: naturalistic thinking humans rarely strive for the optimum solutions, but rather for a satisfying solution. (Simon 1960).

5.1.3 CHANGE IN DESIGN ACTIVITIES

Jones argues that there is not one *universal strategy* that can be applied to all situations and refers to as the frequently "loose ends of design theory" (Jones 1970, 64) in any design activity. A centerpiece of this study is the examination of this data with respect to design activities. The design activities are compared within the cases themselves and across the cases. The study of design activity builds upon a number of design theories and the categories established through such theories (see Table 6). Overall there are many paths, through which the design process can take place. The coded secondary data provides frequencies of categories and their order on a timeline.

The following paragraphs document the path the design activities take in this study. In a second step, it is observed how they change over time and in which sequences they occur.

Differences Within and Across Projects

The four cases (AWM, GCD, EAF, HSU) that had large amounts of messages investigated are different in their total amounts of text units analyzed.

The comparison of design activities has been normalized to 100% of all activities registered during one particular week for each project. Secondly, all stages have been normalized 25 weeks to allow comparisons, since the different projects have different length until completed. Most team members have several different project assignments within their firm and job duties at any given time. Therefore, it is assumed that in some weeks few transactions take place, while in others a very large amount of transactions takes place in any given project. A consideration of percentages balances these factors and allows a more objective view. Table 19 documents the total design activities of all four selected projects, which were compared based on the average of their total design activity in the text units of messages and documents.

Table 19.
Overall ratios of analysis, evaluation and synthesis of each project.

	Design Activity			
Case	Analysis	Evaluation	Synthesis	Project phase
AWM	0.216	0.362	0.422	Design phase
GCD	0.043	0.677	0.279	Documentation phase
EAF	0.247	0.434	0.319	design phase
HSU	0.163	0.330	0.507	Documentation phase

As a first step, the differences and commonalities among the three design activity types are observed within each project itself. Based on a level of confidence of 95% (α=5%) an F-Test indicates that the means of *analysis*, *evaluation* and *synthesis* are significantly different from each other within each project (see Table A-1). This indicates that it is safe to assume the differences in means of design activity types are most likely not random. These numbers in Table 19 are based on approximately 7,000 text units distributed over the four cases.

The statistical comparison across projects testifies that the means of the same design activity types within each project are also different to each other at a confidence level of 95% (see Table A-2). These results show that the four projects cannot be simply averaged across all projects and pooled into one data set. A closer observation is necessary. There are no significant differences between the cases EAF and AWM for the design activity type of *analysis*, according to an Analysis of Variance test and Least Square Differences (LSD) test. Both cases were in the design phase. One might have expected a higher percentage in synthesis for the design phase, but recorded data did not show this. An explanation could be that much of the synthesis took place outside the WBCS, possible in form of paper sketches.

GCD was already in the documentation phase. Many of the messages or documents submitted were the results of discussions, but did not relate to the analysis of the problem. The documents focused on the proposed solution instead. In addition, the case HSU was also in the construction documentation and administration phase. This might explain the predominance of the evaluation and synthesis in these two later cases (see

Figure 10). These later cases had reached a point in the building process, in which most of the actual design should have been completed, and solutions to the problems posted. However, the data indicated that the solutions were still changed or updated by either the contractor or the engineer, in response to the realization of a proposed solution. Hence, the design solution were changed, re-synthesized, and evaluated again. A possible approach to solve this dilemma to reduce the *evaluation-synthesis* activities late in the project could be an earlier integration of the contractor or the engineers in the project in the design phase.

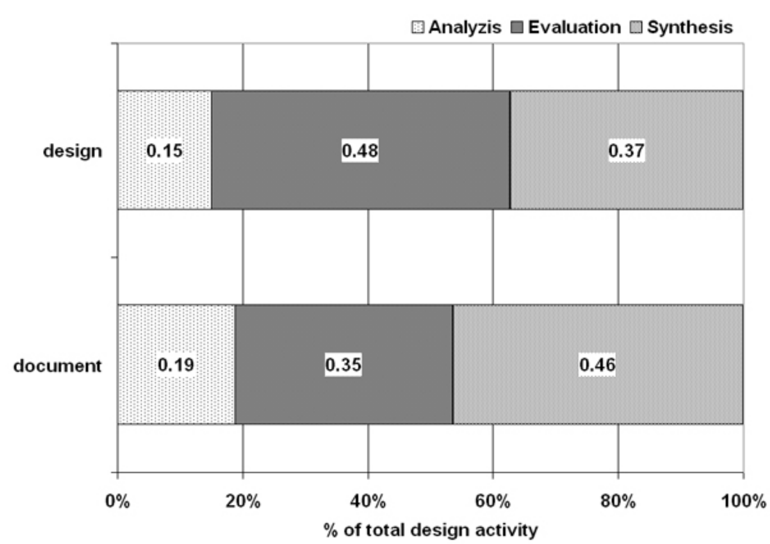

Figure 10. Comparison of design activity during preplanning and design phase versus construction documentation and administration.

Similarities in means and variances in *evaluation* appeared for several combinations of projects. A LSD test indicated that the cases GCD and EAF had no significant differences in *evaluation* (see Table A-2). In addition, EAF and AWM could be pooled together in for the *evaluation* type. This is the same pair of cases, which could be pooled based on the *analysis*. The cases AWM and HSU did not show significant differences between the groups.

Comparing the *synthesis* stage for the four cases, they indicated significant differences between five of the six-pair wise comparisons. A more detailed statistical analysis indicated that GCD and EAF had no significant differences between the *synthesis* groups. This is the second category in which these two cases are similar. Hence, they are only different in the *analysis* part, in which GCD did not have significant text units coded for *analysis*. These statistics require careful observing of the projects based on a significant difference between the design activity types. Figure 11 shows the design phase of cases AWM and EAF combined because their ratios for analysis and evaluation are similar.

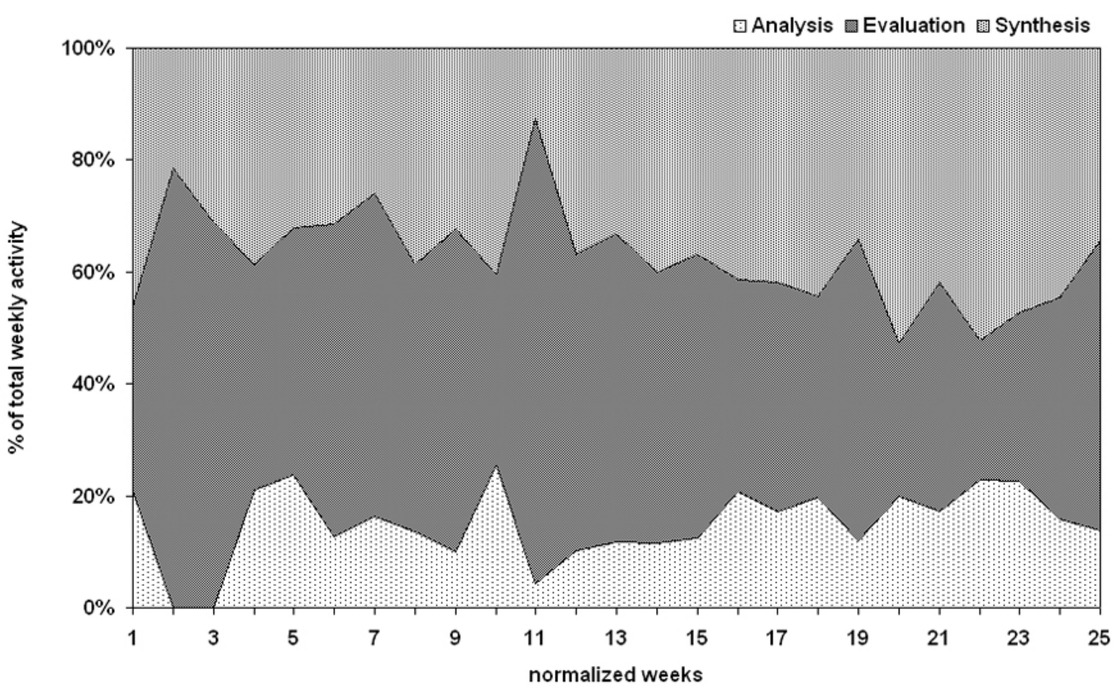

Figure 11. Design activity during planning and design development.

Activity Changes over Time

Following the sets of ANOVA tests are descriptive statistic of the changes over time in design activity. Figure 11 shows that the amount of each type of activity fluctuates in every project, but remains on average considerably steady. Occasional peaks of one specific activity relate to times where the total amounts of messages were low and only a few text units could be coded. These were times when project participants had been assigned temporarily to projects outside this research.

Figure 12 shows the cases of GCD and HSU during construction documentation and administration phase. The most obvious observation is that *analysis* remains very constant across all cases and stages (compare Figure 11). However, it documents that the amount of *evaluation* is declining with the progression of the project. This is realistic, since at some point the architects and engineer decided on a final solution and had to get it built. These findings suggest designing without evaluating or checking, which is consistent with routine and conventional based design.

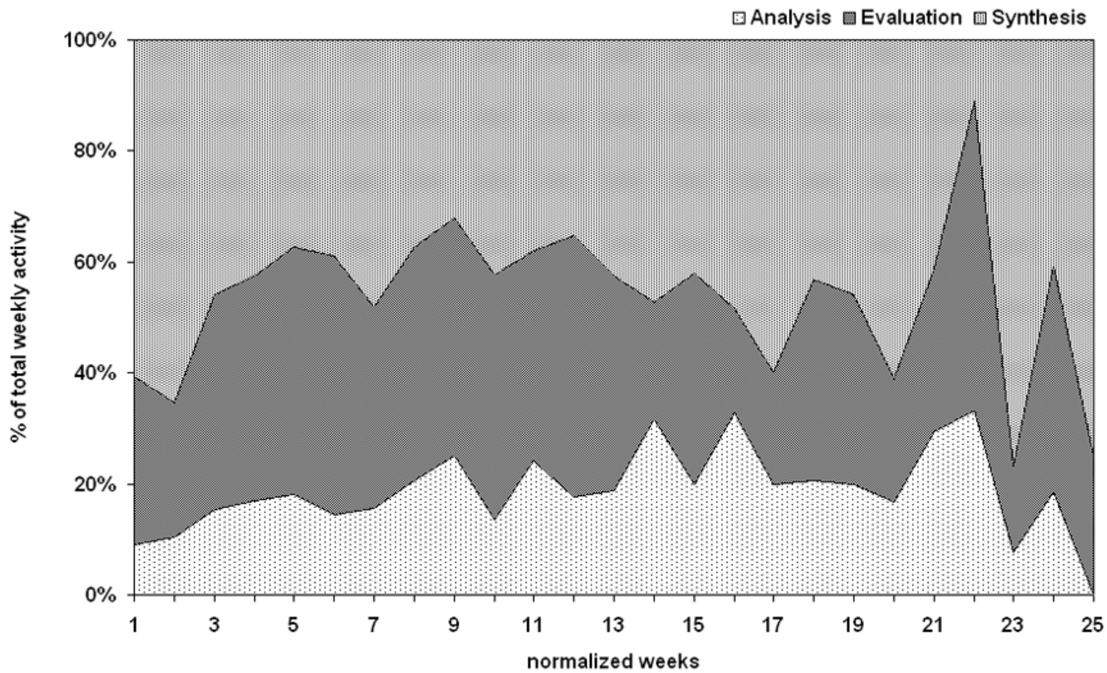

Figure 12. Design activity during construction documentation and administration.

Sequences and Structure of Design Activity

The discussion how a design activity sequence might happen, has been going on for decades. Many researchers such as Asimow (1962) and Jones (1970) have suggested that it is a loop of analysis, evaluation, and synthesis. The following paragraphs investigate the case data to provide a picture of apparent sequences in the project, using stochastic methods.

One question which comes up frequently by many participants and researchers is if team communication is chaotic "in the sense that any sequence of design steps is likely to appear, or are there regularities, with one step systematically following after another specific step" (Stempfle and Badtke-Schaub 2002, 485). To resolve these alternatives, the transition probabilities between all of the steps need to be calculated and then compared to the baselines of the steps. Based on these assumptions, design is interpreted as a particular process (Simon 1960). One goal in process research, as stated in chapter 6 at Poole et al. (2000), is identification and characterization of this process. The identification of sequences and dependencies in statistical modeling helps to evaluate this design process. The modeling is based on the prediction of changes in probability distributions of events as a function of time. Since there is no general or established knowledge of the probability distribution of the three events, the first hypothesis is that all three have the same probability of analysis = 0.33, evaluation = 0.33, and synthesis = 0.33. A potential approximation of the probability in any particular case is generated based on the ratio of distribution of totals of each design activity type divided by the total of all text units coded by any design activity. Therefore, the two hypotheses for the case AWM would be as shown in the Table 20.

Table 20.
Probabilities of design activities in hypotheses 1 and 2.

	Analysis	Evaluation	Synthesis
Hypothesis 1: evenly distributed	p = 0.33	p = 0.33	p = 0.33
Hypothesis 2: based on ratio of overall design activities	p = 0.22	p = 0.33	p = 0.45

This section will apply a model, called Markov chain, to the sequences. For the current design activities study, this matrix of event probabilities is shown as a first-order Markov model below. The hypothesis 1 assumes equal probabilities for each type. The probabilities in hypothesis 2 are the ratio of a type of activity over the total amount of all design activities. Each row must sum up to 1 for any given event; one of the three choices, such as analysis, evaluation or synthesis, will follow. If nothing follows, it will not be registered at all. A minor limitation is the mutually exclusive condition for studies where the coding can be occasionally subjective or just not very clear. This error is compensated through the large amount of data points.

Hypothesis 1:

$$
\begin{array}{r} \\ analysis \\ evaluation \\ synthesis \end{array}
\begin{array}{c} \begin{array}{ccc} ana & eval & synt \end{array} \\ \begin{bmatrix} 0.33 & 0.33 & 0.33 \\ 0.33 & 0.33 & 0.33 \\ 0.33 & 0.33 & 0.33 \end{bmatrix} \end{array}
$$

Hypothesis 2:

$$
\begin{array}{r} \\ analysis \\ evaluation \\ synthesis \end{array}
\begin{array}{c} \begin{array}{ccc} ana & eval & synt \end{array} \\ \begin{bmatrix} 0.22 & 0.33 & 0.45 \\ 0.22 & 0.33 & 0.45 \\ 0.22 & 0.33 & 0.45 \end{bmatrix} \end{array}
$$

The first step for this study is the test if the there is a relationship or a cause behind the distribution of the event sequences. The Chi^2 statistic tests whether the distribution of observed events is significantly different from a pure chance distribution. It compares the actual cell values with the expected, chance based values.. The expected distributions are Hypothesis 1 and 2. This shows, if the actual event sequence is independent of the previous event, or if there is it is causal relationship. A Chi^2- test provides the goodness of the fit of the model. The Chi^2- test compares the expected values (Hypothesis 1 and 2) to the actual values captured from the case data. It provides an indication that, at a certain level of confidence, the model does or does not fit, and if the events are independent or not. Chi^2-tests are more appropriate than other tests, because they allow lower numbers of expected frequencies per cell.

The second-order Markov chain is an expansion of the first-order and will increase the number of rows in the matrix to (types).^{2} This dissertation study evaluates, which sequence is the most frequently observed design activity, using a second-order Markov model. The transition matrixes for the AWM case show the frequencies below. The letter A = Analysis, E = Evaluation, and S = Synthesis. The first column (A-A) provides the first and second event, followed by the event, labeled on the top of each column. The matrices for the other three cases are in Table A-3 to A-6.

Actual Frequencies

1 – 2	A	E	S
A – A	0	0	0
A – E	22	0	25
A – S	30	21	0
E – A	0	26	30
E – E	0	0	0
E – S	15	14	0
S – A	0	24	56
S – E	15	0	36
S – S	0	0	0

Expected Frequencies H1

1 – 2	A	E	S
A – A	0	0	0
A – E	16	16	16
A – S	17	17	17
E – A	19	19	19
E – E	0	0	0
E – S	10	10	10
S – A	27	27	27
S – E	17	17	17
S – S	0	0	0

Expected Frequencies H2

1 – 2	A	E	S
A – A	0	0	0
A – E	10	15	21
A – S	11	17	23
E – A	12	18	25
E – E	0	0	0
E – S	6	10	13
S – A	18	26	36
S – E	11	17	23
S – S	0	0	0

The tests for both hypotheses indicate that actual frequency distributions in the cells are significantly different from the expected values. The actual distribution is not purely a random distribution of frequencies. This concludes that there is a reason behind the actual distribution and it is worth further investigation of the actual distribution. The full comparison of all cases in Tables A-3 to A-6 provides the same results.

Table 21 shows the frequency of each cell, based on a pooled average of all four projects. Statistically, the four cases should not be grouped, but descriptive statistics across all cases document that the highest frequencies appear in the same cells. More than half of all sequences fall into five cells: These cells (marked bold in the Table 21) are EAE, EAS, ESE, SAS, and SES.

Table 21.
Frequencies of sequences of design activity triplets, given event 1 and 2.

event 1 – event 2	A	E	S
AA	0	1	1
AE	61	27	51
AS	59	64	9
EA	9	**103**	**78**
EE	15	0	10
ES	33	**115**	2
SA	5	50	**105**
SE	52	25	**104**
SS	19	0	0

Note: table is an average and based on 1,000 overall units.

Returning to the original thought of design theory as a sequence, based on a more or less closed loop of three distinct activities, each of these sequences (cell) has two associated cells. These cells have the same activity types or events as the main cell. For example a high frequency of the event sequence EA-E should be equivalent to a high frequency of the events AE-E and EE-A, if it is a closed loop. The assumption of being a loop with 3 events is highly likely (Second-order Markov model), because a search for loops of 4 events generated no significant results (Third-order Markov model). Table 22 lists the sums of loops for the four major cases.

Table 22.
Summary of counts of loops for Markov models.

	AWM	GCD	EAF	HSU	Sum
0. order	4335	2177	2285	1538	10335
1. order	915	728	488	236	2367
2. order	314	340	123	60	837

Table 23 indicates the eight possible loops, omitting triplets of single event types, such as AAA, EEE and SSS. These sequences show the same loop, only with a different starting point. Table 23 shows the complete list of loops, sorted from the highest frequency to the lowest.

Table 23.
Loops with the same sequence for the three design activities.

	First instance	Second instance	Third instance	Percentage
EAS or ASE or SEA	**78**	**64**	**52**	**19.4**
ESE or SEE or EES	**115**	**25**	**10**	**15.0**
EAE or AEE or EEA	103	27	15	14.5
AES or ESA or SAE	51	50	33	13.4
SAS or ASS or SSA	105	9	19	13.3
SES or ESS or SSE	104	2	0	10.6
AEA or EAA or AAE	61	9	1	7.1
ASA or SAA or AAS	59	5	1	6.5

Note: percentage indicates the ratio of the sum of the three sequences in the row to the total amount of sequences.

The most dominant is the Evaluation – Analysis – Synthesis loop. This is considered the classical sequence of design activities. There is an assumption for decades that this is the predominant loop, but it only accommodates for 19% of all sequences across the triplets of sequences or closed loops. The second dominant loop with 15% of all three triple-sequences is the Evaluation – Synthesis – Evaluation loop. This is also called the engineering testing, similar to generate and test (Simon 1960). If I would have clustered the data and merged series of the same activities together, it is equivalent with the

SES sequence and its associates. Therefore, the 10.6% could be added to the 15%, which together account for over a fourth of all design activity sequences. This is an interesting finding, because it shows that there is not much Analysis. The designers often propose solutions and their colleagues evaluate them. Theoretically, every time a designer proposes a routine solution based on industry guidelines and experience, such as the *American with Disabilities Act* requirements (ADA), he or she does not analyze anything. According to Schön, where the designer might actually evaluate his own solution before moving on and re-synthesizing. If participants mostly synthesis and evaluate in a constant loop, it would also imply that their ability to synthesize is based on large amounts of tacit knowledge to solve problems. In addition, the loop of *synthesis-evaluation* supports Peña's approach that the analysis needs to be completed, before a designers begins the synthesis and evaluation process (Peña and Parshall 2001). Otherwise, they would need to gather more information through analysis, which they apparently are not doing. This sequence loop goes clearly for the strain of thought to the reflective practitioner.

The variety of loop sequences corroborates studies that are more recent. They assume that designers do not necessarily work in a particular sequential order. Another hypothesis is that their cycle is too rapid to be captured in the case data investigated. However, the data indicates that there are preferred sequences or some sequences are significantly more common than others are. There are occurrences where designers synthesize a solution first, before they actually detect and understand certain issues and requirements of a problem (Suwa, Gero, and Purcell 2000, 540). The fact that there is more evaluation than synthesis relates to the often-mentioned reflective approach.

Particular Design Activities

The previous studies focused on the main categories of design analysis and on how different types are related to each other. A detailed investigation indicates that some of the sub-categories have only very low counts of text units. This low percentage brings up an issue Rosenman, Gero and Maher (1994) pointed out that a too large number of sub-categories could potentially mask relationships and patterns in the data. Therefore, the above test based on the main categories is appropriate. The frequency of the sub-categories is distinguished in three brackets, based on the ratio of the overall percentage of each of the sub-categories over the design activities (see Table 24). The first bracket of major activities is the analyzing of proposed solutions and the synthesis in making decisions. The justification of solutions would be 26% on average, but the average is not representative, since in the GCD case the amount is an outlier. The analysis of proposed solutions is a major part of all activities, based on descriptive statistics. It accommodates for a large amount of all activities across each case, on average 23%. The second bulk of design activity is the decision making. Some of the decisions made during this activity are revised later in the design process and might be more appropriate to place in proposing solutions, but due to the large amount of data, it was more reasonable to leave them in the original sub-category. These findings corroborate the sequencing findings of high frequencies of evaluation-synthesis loops.

Table 24.
Counts of sub-categories of design activities.

		AWM	GCD	EAF	HSU	Average
Analysis						
	Analyze problem	0.11	0.02	0.12	0.02	0.07
	Consult information	0.02	0.06	0.01	0.01	0.02
	Evaluate problem	0.05	0.00	0.07	0.08	0.05
	Need analysis	0.08	0.01	0.09	0.05	0.06
Evaluation						
	Justify solution	0.22	0.68	0.09	0.05	0.26
	Evaluate solution	0.00	0.00	0.00	0.01	0.00
	Analyze proposed solution	0.15	0.08	0.40	0.30	0.23
Synthesis						
	Propose solution	0.07	0.01	0.05	0.10	0.05
	Make decision	0.24	0.15	0.09	0.33	0.20
	Make final solution	0.01		0.03	0.04	0.02
	Describe an event	0.06		0.05		0.03

Note: the sub-categories of calculating proposed solutions, clarifying and modifying solutions are not shown in the table, because rows had no entry for these sub-categories.

The second bracket of medium frequent design activities are mainly in the category of analysis. It documents that analysis is balanced across its sub-categories and has 5 – 7% per analyzing a problem, evaluating a problem, and the need analysis. Applying the design theory of Peña and Parshall (2001), these activities would take place early in the process. The distribution over time does not confirm this. The distinction between analysis first and the synthesis following was either not applied to all studies or not significantly apparent across the projects to be statistically detected. Within this second bracket is the synthesis subcategory of proposing of solutions. I expected to have a higher percentage here, since creating solutions is the main aim of designers. Many designers are “making the decisions,” which needed to be changed. The coding captures these activities under the sub-category of *decision making* rather than *proposing a solution*, which would be more appropriate. This generates a lower than expected ratio for proposing solutions. It shows also that there is not enough exchange or collaboration to generate a more definite solution earlier, which would save many change orders later.

The third bracket of activities is the ones that have barely any activities. The reason can be two-fold. The coding schema is defined a priori to avoid biases, but this can produce sub-categories without hits. This is a common problem in content analysis and has been encountered by many researchers (Al-Qawasmi 1999). A second reason is that the projects did not include these activities. In a future study, the coding scheme might need to be revised to accommodate these findings. It would not change the results of the existing study much, because most hypothesis testing is based upon the categories and not the subcategories.

Outlook and Limitation of Design Activity Study

The study of sequences could be continued on a more detailed level, depending on the data available. The next step would be a more detailed phase analysis of all documents and messages available. In a phase study, the consecutive occurrence of the same design activity type in a sequence is merged into one unit. For example a sequence of E-A-A-S-E-E would be boiled down to E-A-S-E as described in chapter 7 by Poole et al. (2000). This allows one to run the above test again and to identify long durations of the same activity type. It can create the loop of certain sequence, regardless of how long each type takes. The reason why I have not conducted a phase study is that most documents are not long enough to do so and the number of two-event-sequences that are of the same type is very low (see Table A-2). This method would smoothen any sequence, if there are sequences that have the same event following each other (Poole et al. 2000, chapter 7)).

This study finds similarities to the design theory and the studies posted by Gero and others (Gero and McNeill 1998). The design theory is not as apparent in praxis as the researchers, which based their findings mainly on experimental studies, posit it. In reality, there are many environmental and organizational factors, for which the theory cannot account. Overall, the design activity theory cannot be fully confirmed with this study nor be dismissed. The main difference between the data in experimental studies and this exploratory field study is the granularity of the data. Most text units are likely to reflect several minutes or phases of project work versus seconds in controlled laboratory experiments. In their 1998 study Gero and McNeill (1998) have shown that design is in fact a process that consists of a series of distinct events that occupy discrete and measurable periods of time. However, they mention the granularity of these distinct periods is within seconds. One study indicates that the span is around 30 second. Gero and McNeill show that in situations with expert designers, the time lag is even shorter than 30 seconds.

The strength of my study is the amount of data that allows statistical modeling combined with data from natural experiments. The application of computer supported coding and analysis allowed a more detailed study than previous laboratory experiments. However wider range of cases might be able to resolve the design theory and its sequences in the near future.

5.1.4 RELATION TO ORGANIZATIONAL HIERARCHY IN FIRM

Related to the hypothesis of work task is the question: *who is going to do the work?* The question this study tried to answer is which work tasks are performed by whom in the different project stages. Dividing all messages and transactions based on content analysis into collaboration and coordination tasks addressed in each message or transaction, the following picture can be drawn in relation to the hierarchy of authors.

Coordination took place more in the middle range of hierarchy, such as lead engineers and specialist (see Table 25). At the specialist and administrative staff level, collaboration or exchange of information dominated. This is interpreted as that the specialists produce the results, but are coordinated by their leaders and directors. The data combined with a detailed study of the content of the messages indicates that a high percentage of information was routed through the team leaders instead of directly addressed to ultimate receivers, who produced the final product.

Table 25.
Task versus hierarchy of employees (Laepple, Clayton, and Johnson 2005, 462).

Tasks	Exec.	Direct	Lead	Specialist	Intern	Staff	Total
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%

Technically, WBCS did not limit communications across hierarchies and firms. WBCS rather encouraged it. The software supported non-hierarchical interaction among team members, and most information was routed along company hierarchy lines rather than directly to the ultimate receiver. In these cases, the software design did not match the organizational structure. Under the assumption, that a high-ranked employee in a firm is assigned to more than one project at a time he or she might not contribute as many messages to a single project as other team members.

Table 26 indicates that most of the accessing or reading of electronically available information took place on a specialist level. Based on the log information available in my study, it could be observed that frequently team members send *new* or *process* information to their staff assistants for submission or distribution into the WBCS. The messages or information was then processed and presented outside the WBCS to the team leader. The team leader then submitted the newly generated or processed information into the system. This is similar to the traditional way of doing business, by delegating tasks to subordinates, who monitor the flow of information into and out of an executive office, although everyone could directly send information to the intended ultimate receiver.

Table 26.
Information handling behavior versus hierarchy of employees (Laepple, Clayton, and Johnson 2005, 462).

Inform.	Exec.	Direct	Lead	Specialist	Intern	Staff	Total
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%

Sophisticated innovation requires a very different structural configuration (Mintzberg 1979, 337). Several of the teams would match Mintzberg’s definition of adhocracy, a configuration “consisting of organic structure with little formalization of behavior and extensive horizontal job specialization based on formal training.” The professional specialists, such as architects, are grouped into functional units for housekeeping purposes, but are deployed as small teams to do their project work. Regardless of the definition of teams, teams need to have a mutual agreement to work together and reach a mutual adjustment as a key coordination mechanism. This fact compared with the data from the WBCS cases indicated that the teams did not communicate across the firms' hierarchies, without staying along hierarchy lines. Selective decentralization of these teams can be located at various places in the organization and involves various mixtures of line managers and staff and operating experts (Mintzberg 1979).

The relation among team members is still on the traditional end. The technology is ready to support more advanced and ad-hoc team structures, but the teams and organizations themselves continue use the traditional channels of communication. This is a major area of possible improvements for firms. However, hindrance to this advancement might remain the liability concern and *old* established standard of care thinking in the industry. This posits the question, if there are differences among occupational characteristics. Does the difference affect the use of WBCS.

5.1.5 RELATION TO OCCUPATIONAL CHARACTERISTICS

A test of occupational characteristics versus work tasks, such as collaboration and coordination showed an indifferent picture. The proportions of collaboration versus coordination of one occupational group were not significantly different from the overall proportion of coordination versus coordination. It could not be documented that certain occupational groups do more coordination or collaboration.

The changes in work tasks were depended upon the project stage and the organizational hierarchy of the sender. They were not depended upon the occupation of the sender. Possibly a broader sample could produce a significant picture of these factors

5.1.6 INTENDED RECEIVER

All messages and transactions could be differentiated into two groups, whether they had an intended receiver or not. And if they had an indented receiver, were they addressed, routed or sent directly to the intended role or group or not? The software provided channels that had informative character to the entire project team, such as announcements and link farms, which were posted to the WBCS without an intended receiver. The second group of WBCS functions included documents, emails, and notifications that had a receiver.

In the cases studied, the software used appeared to have influenced the routing of the information (see Table 14 and 15). System 3 had a default setting, which required a concrete receiver being specified by the sender. In System 1 and 2, a receiver was not required to be specified to submit any information. The quantitative data in case 5 and 6, which employed system 3, used primarily defined receivers (70% of all messages), because it involved RFIs. The cases 2 and 3 used the WBCS as a document repository. However they had employed a well-defined index to group and search for documents. The system was used as a *pull-system*, in which means the it is the receiver's responsibility to find the required information. Cases 1 and 4 were using systems 1 and 2 relied on a system of categories, to sort and classify each document. The users knew the category for which they were responsible and could browse the repository by the latest entries in their respective fields of responsibility.

The problem of no intended receiver is that if participants attempt mutual understanding through interaction, they must share information and confirm that the information has been received and is understood. In the cases of *pull-systems*, this is not automatically provided. The WBCS faces these hurdles not only in information sharing but also in confirmation (Crampton 2001, 348).

The fact that receivers are not addressed in most messages was a serious drawback using the WBCS. The systems do provide a direct routing, but it is contingent upon the sender entering the receiver's name, if the WBCS should not just be used as a document repository. This is significant for non-co-located team members, who cannot walk across the hall to ask their fellow team members, whether they have received any information or document.

5.1.7 LOCATION FACTOR

The use of communication through WBCS was more than twice as frequent among remote members than co-located participants. For this study, central offices are considered those that have more than 10 project members or are part of a corporate headquarter of a participating firm. Remote located team members contribute over twice as many transactions than members located in headquarter offices. Cases 1 and 4 involved multiple offices of international firms, consisting of architects, engineers, planners and consultants. Each project member, remote or centrally located, averaged 141 transactions over a 50-week period (see Figure 13). Members of remotely located offices used the system more frequent, with up to 310 transactions.

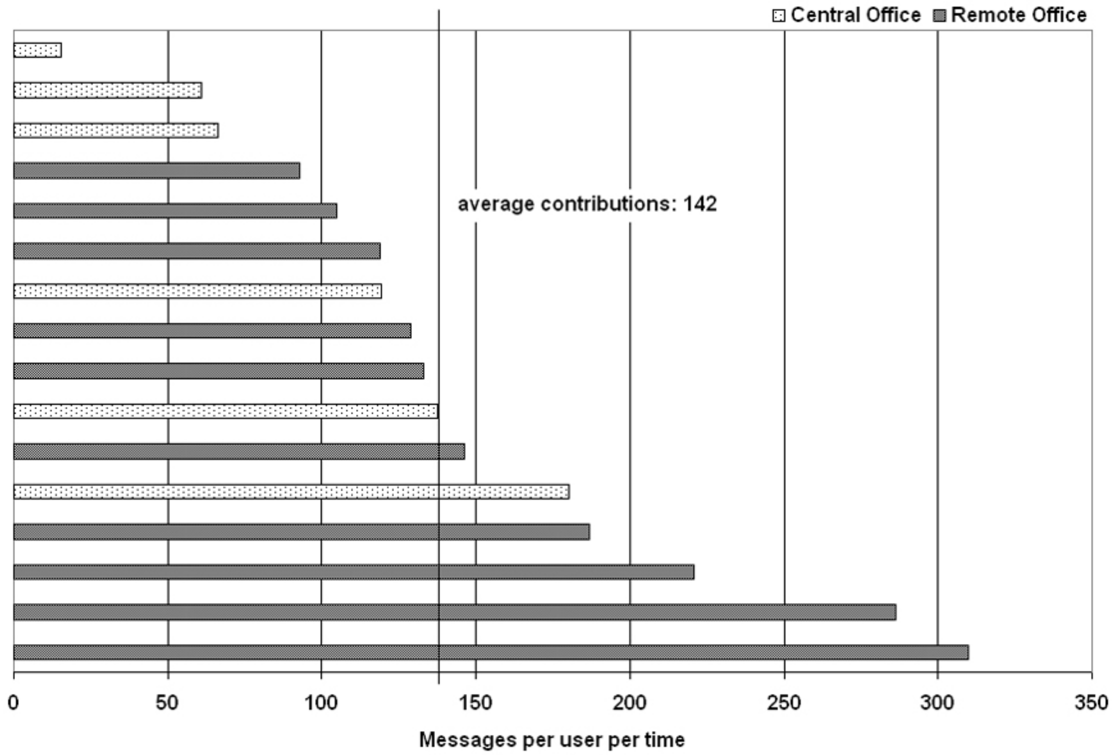

Figure 13. Average amount of activities per user based on their locations.

This result is not surprising as one might expect that project members, who are geographically far from any primary location of the project, would have to rely more on telecommunications, including the WBCS, than others. However, research has shown that geographically distributed and asynchronous communication must be much more explicit than same time/ same place verbal interactions. The increased level of explicitness for the geographically distributed team member might explain higher numbers of transactions (Nunamaker 1997, 367). A different reason might be that some of the remote located team members might have preferred written media. They might had have language barriers to speak up in face-to-face meetings. Written media gives them the chance to better articulate them and to think a concept through before communicating it. For evaluation of this factor, demographic user data needs to be captured in a potential future study.

5.1.8 SUMMARY

At the very beginning of any study, researchers cannot predict, if the data and the tests provided the evidence they were expecting. The testing of the above hypotheses produced several results, some clearer than others.

The content analysis of the content variable is the most interesting. The test on work tasks produced a solid image of how the tasks change with the progression of a design and planning project. It is similar to the tests of information handling behavior, which indicated the vast amount of reading or accessing data without participants immediately processing and resubmitting the data. This showed that WBCS are used as a document repository. In a future study, it would be worth to investigate the level of abstraction of each piece of information to further investigate information, which is used in the design process.

The coding scheme of design activities outlined an understanding of the sequencing of the design activities and applied a second-order Markov model to the process. The combination of both techniques allowed statistical testing, which showed the typical sequences, assuming closed loops of three events. The next step for this test would be a phase analysis in terms of models and a better or redefined sub-category of design activity coding.

The middle range of hypotheses tests was based on a correlation of form and content variables. The observations regarding hierarchy in the firm showed that WBCS and the organizational structure within the firms are a partial mismatch. The comparison of occupational characteristics to work task produced indifferent result.

The hypotheses questioned on form variables produced different results. The location factor confirmed a common believe that remote located personnel used the online system more frequently than others did.

The original attempt to draw a complete path of information flow from the sender to the receiver did not succeed. Mostly, because the majority of information is not directly routed to an intended receiver and back or the receiver is not specified by the sender. Documentation and messages ended up in the common storage facility. This is a serious problem for fast and efficient processes in the future. An attempt to code an assumed receiver based on the content of a message was not possible, because the use of nicknames or not specified names made it infeasible.

Overall, the coding scheme was a success for the channel, the sender and the content categories, except the fine subcategories of design activity.

5.2 CORROBORATING EVIDENCE FROM QUALITATIVE SOURCES

The limitations of the quantitative content analysis of these samples were that only recorded data could be analyzed. The amount and type of data that was transferred through other means than though WBCS, was quantitatively not documented. Capturing this outside information was not feasible in this study. Other means are necessary to capture the information transmitted outside these Web channels. This is valuable knowledge, because it documents the deficiencies of the software or the organizational work structures in the AEC industry. Future improvements are necessary to store the entire project information.

5.2.1 MISSING INFORMATION

A large amount of project communication and documentation was stored in the WBCS. Based on the review of the available documents and a comparison of common business practice, some types of communication were not stored in the WBCS. All electronic documentation was stored, except email communication and files that were stored on in-house data servers. As mentioned above, the data was based on written documents; the verbal conversations are usually not documented in a *word-for-word* form. Several of the discussions were summarized or submitted as meeting minutes and discussion notes, occasionally even as telephone notes. For the purpose of this study, the verbal communication was secondary. Nevertheless, it would be worthwhile considering capturing this information in future studies, applying the same analysis methods.

Email

The majority of written documentation that was not captured was exchanged through corporate email systems. According to discussions with practitioners, email is at least subjectively, the most commonly used asynchronous communication system among participants. The reasons are the ubiquity and the familiarity of users with the software. The system 3 provided a built in email function, but it was not used. Case 5 showed a few incidences where it actually was used, but too few to derive any repetitive pattern.

Since all team-members had corporate email systems already in place and had to work on various projects at any given time, they needed to have one address to be reached at, if it was not their physical desk.

A second advantage of the corporate email is that members outside the WBCS can contact participants at any given time. Since WBCS logically requires authentication, new members cannot access or use the WBCS built-in-email function, as long as they are not fully integrated in the project team and become users on the WBCS.

The disadvantage of the individual email is that it is by default stored in a personal inbox folder structure. It is not accessible for other team members, if the original recipient does not provide access to the project emails in his or her inbox. One hybrid function to overcome partially this problem would be the use of shared email-folders on corporate email-systems. This requires that the user have to setup filters to move important emails into these shared folders. Obviously, there is currently no ideal solution. A re-routing of email through the WBCS would be ideal to allow a complete repository of all email in the common and shared document repository. A re-routing would allow to read the emails in the own corporate email client, while being reachable by everyone.

Corporate Server

A portion of written data was stored on corporate data servers. According to the users, this was often general information spanning several projects or was related to large files, such as drawings, which were considered storage intensive. The actual amount of that data could not be measured.

5.2.2 PARTICIPANTS' DISCUSSION

Based on the discussions with several participants, they reported their main concerns regarding the WBCS. The questions are primarily focused on the reasoning why WBCS was not used or the hesitance to use it.

Security Concern and Trust

A major concern for many users was the reliability and security of information being stored in safe location. If participants cared where information was stored, they considered the physical location of data being critical. All WBCS stored the data on secured third party locations.

According to the literature, people frequently are hesitant to provide their knowledge and experience to the extent possible with others. This is problematic in any case of collaborative work and negative impacts the shared project goals. During the discussions, the interviewees did not particularly voice this as a concern. Their concern is confidential information to remain confidential and accessible to only a limited group of participants if it is stored on WBCS. From a technological point of view, this is not a valid excuse, since the systems do allow setting securities on a per file or folder basis. The real reason might have been the fear of individuals to lose personal competitive advantage across firms and within firms.

Familiarity with Software and User Friendliness

More impact than the trust issue is the familiarity with technology and how it is supported throughout the firms. Consistent with literature, if a company has a champion using any given system, the acceptance among users is higher, based on subjective comments from participants. In one example, the team used the WBCS very successful. Other teams within the same company followed, adopting WBCS. This internal development encouraged the use and fostered the system development, once a champion was found.

Many participants interviewed were senior personnel. I would have expected that they were more hesitant to use the new technology, but they mentioned that computer generation difference is less an issue of actual use. It is often more an organizational question, why use new technology, while the traditional methods are still functional.

Everyone mentioned the actual complexity of the WBCS. In general, participants only use a few functions that they believe are helpful, which is a small subset of the capability of the entire system. The complaints are that either the system is too difficult to use or the functions are not necessary. This is consistent with the quantitative findings in cases 5 and 6, where only five functions were used out of ten available functions.

Financial Constraints

The firms that used system 3 reported that the financial constraints played a major role in using the system and its extents. Since the initiating companies were billed by the number of seats on a project (= number of participants with logins) and the amount of data stored within system, they tried to limit the seats and data stored. They stored only the most current information within WBCS to avoid high charges for storage capacity by the software provider and host of the server system. This undermines the concept of having the entire project information available. In particular, the interest in the design rational, which users or project participants might be interested in, who join a project team at a later stage and who are not aware of previous decisions.

The system 1 was developed in-house, because the main decision makers were convinced they need to share project information among their global team members. They calculated that an off-the-shelf solution would be too expensive and that they only needed a few functions, out of the large array of functions offered off-the-shelf. The firms in discussion associated much potential with the systems, but were not completely satisfied with the systems available off-the-shelf.

5.2.3 SUMMARY

During the discussions, a number of disadvantages became clear. All project partners have to keep the information they provide up to date on one centrally stored location to ensure consistency. The effectiveness of the system can only be ensured, if team members refrain from using alternative means to distribute information, such as email outside the WBCS and others.

From a corporate perspective, non project-specific information should be available beyond any particular project Website. It becomes apparent that the distinction of project specific information and non- project-specific information became distorted using WBCS. The finding of *evaluation-synthesis-evaluation* as a frequent sequence of design activity suggests that much information was not very project specific and did not require project particular *analysis*. Much information might have been drawn from an alternative source, such as previous knowledge, practice rules and guidelines.

The corroborating discussion implied that the problems with WBCS are financial constraints and traditional organizational structures that prevent the full potential from materializing. The financial concerns might become less in the near future, when storage capacity more affordable. The organizational issues need a champion and a clear structure within the organizations to adjust the work patterns to the system and vice versa to integrate the new technology.

5.3 ANALYTICAL EVIDENCE

The synthesis of experimental, statistical and interview data produced evidence of how the WBCS is currently used. It answers: what can we learn from tens of thousands of communication and transaction records: the quantitative data collected from the software was used as the core of the analysis and synthesis. The discussion with practitioners added qualitative data and explained more of the non-documented information. The theory referred to in the literature review bridged both and helped drawing conclusions. This triangulation produced some of the following conclusions and indicated the significance of this study.

5.3.1 INTRODUCTION

The weakness of the system is that users often do not appreciate the intrinsic value of the system, extracting information from the repository. Many never considered searching the repository to check what information and knowledge was available to them. This also indicates that a good search function or indexing procedure is mandatory to utilize fully WBCS advantages. Only the system 2 had a decent indexing capability.

The lack of awareness of the intrinsic value reduces the commitment of the participants. They might not introduce their most recent information back into the system that could help others if they do not appreciate it themselves. This relates to Ciborra and Suetens' (1996) concern, that there is sometimes no sense of ownership. This results in lack of attempts to cultivate their collective information capital.

5.3.2 MAJOR FINDINGS

The major findings, beyond testing of the hypotheses, are related to the AEC's organizational structure of the firms in relation to their use of software that supports their mission. The match and mismatch of organization and technology influences the use of WBCS and its potential to support the AEC planning and design process. The data obtained described a good picture of the collaboration and coordination efforts in the industry. These efforts showed how the design process using WBCS took place and related to existing theories of design activity.

Organizational versus Technology

Introducing new technology is always of concern for the management and the employees of any firm. In particular, in the AEC industry, the adaptation of new technology is a very slow process (Teicholz 2004). Traditionally the AEC industry is resistant to change, if it involves the way in which business is conducted on a daily basis. In firms, which had a champion and had technical support, the systems where used more than in others. Owners and clients can force architects to use WBCS, but it was used more extensively, when the driving forces were within the firm. It is insufficient to deployment simply a new technology; it requires adaptation to the new ICT. Changes in the organization and its behavior itself are not unavoidable (Jackson and Poole 2002). The acceptance of this fact will decide, if the software is a success or just another tool.

Utilization of WBCS

The WBCS was well used by remote located participants. It was mostly used as a document repository, scheduling and project directory tool. The real value was only then encountered, once every team member contributed all project knowledge and trusted its colleagues. The drawback is, if not all information was entered and data became outdated. Even so, WBCS did not require a project administrator; all systems had a person that cleaned up the system on a regular basis. Comparing the different stages, the use during the construction documentation and administration appeared to be more successful than during the design phase.

The WBCS is essentially a data repository. All users need to be aware that the quality of any repository is only as good as the feed into the repository. The data stored in the system is very unambiguous information. It is documentation of proposed solutions, which become final synthesis, if there are no more questions by other team members. This is consistent with ideas of media richness that stored data has less uncertainty than face-to-face communication (Daft, Lengel, and Trevino 1997). The asynchronous modes produce outputs that are more concrete. However, the problem with lack of consistency of information feed is a common problem. Every user needs to commit to sharing and contributing the information and knowledge available to him or her. The system becomes productive as participants appreciate the value of the system (shared paradigm).

This shared information space can be highly effective, if all team members share the common goal of providing a high level of corporate knowledge. Nevertheless, the fear of losing personal advantage through obtaining *unique process knowledge* needs to be overcome.

Collaboration Issues

The major goal in using WBCS is to foster collaboration. The data showed that collaboration accounts for half of all work task related content transmitted through the online collaboration tools. However, there is a lot of workflow organization behind it to achieve this level of collaboration. Studies have suggested that frequently people think they are working collaboratively, but they are actually co-operating and, even more important, compromising (Kvan 2000, 413). The process of collaboration can be time consuming. It requires time to establish the team environment to work successful together. Data shows that a certain amount of time is spend on an individual basis. Collaboration as it takes place through the mostly asynchronous media of WBCS requires participants to submit data to the system, as they believe the data content has reached a stage to submit them. However, the content of the data showed that individuals declared the data prematurely as final decisions (see Table 19). They do not wait for input from others to declare it as final solution. Hence, it was observed that the data needed to be changed and resubmitted. Summarizing, the collaboration in WBCS frequently takes place in terms of a back and forth of information exchange between participants, rather than working synchronously. On the other hand, the alternative is that the collaboration as it is practiced in this case study is not as perfect as it should be, because solutions are made prematurely and require revisions later. This is what makes the architecture industry inefficient or generates major losses caused by change orders.

Media Affordance

Information technologies has been praised as a magic tool and has great potential. However, media has it limitations. The findings document that WBCS is excellent for the overall team information flow, such as scheduling, announcements and general data repository. Yet, it has its drawbacks not just at an organizational level. A major problem with project Websites is that they are document-based and draw a line between project-specific and project independent information. As explained above, documents are moved away from their original source to a central storage location during the project, as third party storage becomes expensive with an increase in data. Information that is in principle independent from projects, such as information describing the products and services of a company, becomes project-specific, if it is entered into the project Website. It might be stored elsewhere better, since it is part of a corporate knowledge and could be applied to other projects. Therefore, this information becomes disconnected from its source and from the underlying business processes. Van Leewen and van der Zee (2005, 495) suggested that this can become a considerable risk, because it might generate outdated information by hosting the same information in several locations.

A second lesson learned is that media should has to accommodate all channels users traditionally use, like email, or needs to provide an equivalent channel of the same affordance. This holds at least as long as no organizational changes take place to accommodate the online collaboration tool. Otherwise, the WBCS cannot appropriately support the tasks architects and engineers conduct. The large percentage without an intended receiver is not ideal. Data is available in the system, but it is not utilized because the *end-user* is not aware of its existence. This leads to the demand for search capabilities that are still missing in most WBCS. Some may argue that the system does not afford any visual and auditory cues, which researchers claim to be essential for collaboration (Kraut et al. 2002). In the absence of this capability it must be compensated for by a different work approach.

5.3.3 LIMITATIONS

The limitations of this study are the small number of cases, in which owners and the participating firms agreed to provide unfiltered project information. A future study should include a wider spectrum of projects to increase the generalizability of the research. Carrying this further, the ultimate goal would be to have projects, which are tracked and captured from the project initiation to the building operation. This could help to complete the picture of a full building life cycle of information flow. The same data might also be helpful to establish building information models for the AEC industry. This future project should include records of verbal communication and email, to complete the picture of the entire project communication.

When I would repeat, I would redefine the coding system further, by redefining some sub-categories and better differentiate the sub-categories. At this point, the techniques of coding are heavily dependent upon the human coder and upon the training of the computer. A future project could significantly benefit from this training and might be able to achieve higher coder reliability. The difficulty in this study was that there was no documented AEC study of this scale to compare the results of the coding book and the coder reliability. The baseline of comparison was derived from theories and techniques from related fields outside architecture.

6 SUMMARY AND CONCLUSIONS

6.1 INTRODUCTION

This research produced unique results on various levels. The original question was *how WBCS are used in a daily work environment at architecture and engineering firms*. The results answered this from several perspectives based on changes of information and content types over time. It describes how WBCS relate to the organizational structure in the companies using the system. In addition, it answered a significant question on a qualitative level, regarding information that had not been transferred through the WBCS and why. These findings are related to theories and interpreted so future WBCS can be improved. Organizations can gain expertise on how to use them and how to adapt to them.

A research methodology has been employed that was previously not used in AEC at this scale. Using computer-supported content analysis allowed generating statistically valid quantitative results. Independent of the actual research results, the application of this method will help future researchers to process large-scale data sets and to make sense of information available from case studies. The method is very capable of applying coding schemes with form and content variables based on previous literature. In particular, using design theory and coding the messages and documents for design activities achieved good results. The data showed that certain orders and sequences of analysis, evaluation, and synthesis are much more prevalent than others are. Summarizing, the adapted research methodology documented the use and not-use of WBCS in AEC industry. In addition, it produced an image of collaborative practice in AEC and how design activities take place in a complex environments.

6.2 RESEARCH METHODOLOGY

Logging the use of Web-based communication for research purposes has not been conducted at this scale. This research used existing data from practice at a large scale. The entire data set of each case has been created while the industry practitioners were designing, planning and documenting actual building projects. The data, which included transaction logs, messages and various types of documents, has been collected electronically from participating companies. The data was then gathered and merged by information type into the master database, housing all project cases. This complete dataset has been converted into secondary data through content analysis. The categories of the content analysis are defined a priori based on existing theories. The content analysis covered the three form variables of sender, receiver and communication channel, and the content variable. The content variable included coding for information handling behavior, work tasks and design activities. This research transformed existing techniques from other fields, such as communication, organizational theory and engineering, and applied it in a quantitative fashion to architectural research. It is uncommon to conduct quantitative research in communication in architecture, using large samples from practice. The results have proven that the technique is very applicable and capable of producing statistically solid evidence of design activity, collaborative processes and use of WBCS in AEC industry. Future research can adapt this method and apply it to large data sets to conduct further studies in AEC.

6.3 INFORMATION WBCS DOES NOT TRANSMIT

This study showed what type of information was not transferred through the system and what was not entered in the system. As explained above, it did not capture any verbal communication, except meeting minutes. Of the written and electronically available data, it did not capture project emails. This is mainly because of an inconvenience to the user. Team members are usually involved in several projects at any given time and do not want to log onto several different systems, to check for messages for each project separately.

Part of the project information was communicated in phone conversations and was never documented. This is similar to the traditional office procedures. It is important to note that many participants had apparent concerns providing personal knowledge and feeding it into a shared knowledge space, where they did not know who reads or even controls it. This is a behavioral and social concern rather a WBCS concern. However, it is a significant factor that influences the usage of WBCS and requires further research..

WBCS did not store the companies' project-independent information. However, this is a two-sided sword. On one hand, firms should capture reusable information in a central location to be able to draw from that information at a later project, on the other hand, if information is not in WBCS, participants outside a particular firm do not have access to it. To solve this dilemma, organizations have to rethink the way they want to deal with non-project specific information and information sharing.

The last type of information not available in the WBCS, was past project information or previous data versions of a particular piece of information. The original intent of WBCS was to provide one data repository, which is accessible 24 hours a day and 7 days a week for everyone. This has the advantage that project members joining late in the project could retrieve past versions and gain a quick understanding of the project. Due to the financial constraints, data had been moved too soon to a different location to save cost and was no longer available. This might have pulled information out of a particular context and made it hard to reuse later.

6.4 ASSESS ADEQUACY OF WBCS WITH RESPECT TO THEORY AND SUBJECTIVE ASSESSMENT

One objective of research in information systems, such as WBCS is gaining knowledge and understanding that “enable the development and implementation of technology-based solutions to heretofore unsolved and important business problems” (Hevner et al. 2004, 10). This research produces comparisons between WBCS and theory relating to design and communication theory. It provides reasons to adjust the software or the business organization. The research documents the subjective assessment of users towards the WBCS, providing evidence for the architecture and software industry, regarding how the communication systems are established in AEC. This research suggested questions regarding the existing assumptions of design activity in practice.

The data showed that team members, which were geographically distributed, used in particular WBCS. They used WBCS more than twice as frequent as centrally located team members, consistently across the various project phases. The majority of participants used it as document repository. In particular, in the early stages of the projects, up to 90 percent of all information handling behavior is *accessing* and reading of information. The remainder is *generating* new information or *processing* and resubmitting information. This percentage declined with the progression of the project through the life cycle of the building and planning process.

WBCS might be called online *collaboration* systems, but they are more than collaboration tools. The amount of coordination related tasks of WBCS data accounts for almost half of all activities on average across all projects and stages. It is used as a project information base, providing announcement and calendaring features. Future research should investigate, if many of the coordination tasks could be automated or programmed as a logic into the system. This could be further developed into an automatic information routing system.

Certainly, the real strength of WBCS was the document repository function, since it is accessible through the Internet. If storage limitation can be overcome and it provides all project related information, it has great potential. Nevertheless, the difficulty remains that participants must keep the information on WBCS up to date, as they work with it. They may not store new or updated information outside the WNCS. Team members must stay committed to the use of the system. It is crucial that the organization supports the WBCS and that the participants involved adapt to the use of the system. This is the real difficult part of the implementation of such tools.

The data provided insights in the organizational issues of the collaborative practice and the while using WBCS. Coordination took place in the middle range of hierarchy, and collaboration or exchange of information took place at the specialist and administrative staff level. This can be interpreted as the specialists produced the results, but are coordinated by their leaders and directors. It also documented that much communication was routed through the team leaders instead of directly addressed or sent to the ultimate receivers who have to produce the final output. This shows that the implementation of the software was not supported by an adjustment of the organizational structure. Alshawi and Ingirige (2003) commented that the absence of proper assessment of business models that suit an adaptation of information and communication technology can make an implementation fail. “This lack of a strategically driven implementation approach has resulted in resource wastage and unrewarding investment” (Alshawi and Ingirige 2003, 362).

6.5 COLLABORATIVE DESIGN PRACTICE

The entire study is based on existing communication among participants in the AEC industry. The research produced an image of how collaboration is currently conducted in practice, in particular using digital means of communication. Participants communicate with another directly through the medium of the shared space. Shared space exists wherever there is effective collaboration (Schrage 1990).

The large pool of design activity within all the documents and the messages provided raw material to study design activities. Of course, the granularity of the data available was different from previous literature or experimental design protocol studies. Text units coded reflected segments of likely several minutes occasionally. The results were astonishing. Architects and engineer relied much more on their own knowledge than theory assumed. Theoretically, *analysis* accounts for a significant amount of design activity at the beginning of all design processes. The data showed that a larger amount is *evaluation* and *synthesis*, which is equivalent to engineering test principles. Designers rather rely on their own knowledge than consult outside sources.

The analyzed data allowed using a second-order Markov model of the design process. This enabled testing of possible sequencing of events and processes. The results showed that the most frequently observed loops of sequences, based on triplets of events are *evaluation-analysis-synthesis* and *evaluation-synthesis-evaluation*. This indicates how design activities are conducted in practice versus the theory.

6.6 SIGNIFICANCE

The significance of this research is that it contributes to the body of knowledge. The methodological approach is a contribution that does not depend on the specific data results. The research explains vital characteristics of the AEC industry that can increase the productivity and quality of architecture projects, in a future where IT becomes more vital than ever before. The documented communication patterns laid out typical flows of coordination and collaboration.

The building sector is entering a new era. Currently the majority of architecture firms could technically utilize WBCS, since it is readily available on the market, but many firms are very skeptical. The analyses indicate where the software produces hindrance towards conducting a successful building project, and makes recommendations to improve the software. It spells out concerns regarding slow changing organizations. The knowledge of WBCS usage and its patterns in the AEC industry allows advancing software that can support the AEC work structures better. It points out requirements for the software, reducing barriers of acceptance, and reducing potential for data loss during communication. Better software will increase the speed of project processing, which will result in financial gains or savings for the industry and owners. As described in Jabi (2000) and Johnson and Kolarevic (1999) developments in ICT have an impact on the entire building life cycle.

The last significant finding made in this research is a statistical study of sequencing of design activities. This study shows for the first time that particular sequences, previously only studied in theory or as experiments, dominated the architectural practice, based on the data provided. The most frequently appearing sequence was *evaluation—analysis-synthesis*, which had been assumed by Asimow (1962) and Jones (1970) as *the* design theory. However, the second most frequent sequence of *evaluation-synthesis-evaluation*, which confirms that the opposing theory *the reflective practitioners* also has validity (Schön 1983). The coexistence of both theories is an interesting finding.

6.7 FUTURE RESEARCH

Upon completion of this study, what should come next? A broader data sample would be very helpful to increase the generalizability of the findings. Additional samples that span the entire building life cycle would be able to support the modeling of building information and a decision path model within the industry. If a large set of samples becomes available, a phase analysis could create a decision matrix and model the flow of information in the AEC industry. Therefore, simulations and models could be created towards a building information model.

The same content analysis methodology, with improved definitions of sub-categories could be applied to the wider sample. Parallel with improved sub-categories, other theories or coding schemes other than the ones used could be tested for applicability. This would foster the development of more computer–supported coding schemes for the AEC industry.

What become very apparent in this study that the overall the socio-technical aspects of technology integration in the AEC need to be studied in more depth. They cannot remain anecdotal; they need to be qualitatively and quantitatively researched, since there impact on the successful integration is vital.

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APPENDIX

Table A-1.
Group-wise comparison of design activities within each project.

Summary and ANOVA: AWM						
Groups	*Count*	*Sum*	*Mean*	*Variance*		
Analysis	24	5.188	0.216	0.002		
Evaluation	24	8.690	0.362	0.013		
Synthesis	24	10.122	0.422	0.008		
Source	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.537	2	0.268	35.184	0.000	3.130
Within Groups	0.526	69	0.008			
Total	1.063	71				

Summary and ANOVA: GCD						
Groups	*Count*	*Sum*	*Mean*	*Variance*		
Analysis	16	0.696	0.043	0.008		
Evaluation	16	10.832	0.677	0.021		
Synthesis	16	4.472	0.279	0.012		
Source	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.280	2	1.640	121.664	0.000	3.204
Within Groups	0.607	45	0.013			
Total	3.887	47				

Summary and ANOVA: EAF						
Groups	*Count*	*Sum*	*Mean*	*Variance*		
Analysis	9	2.227	0.247	0.010		
Evaluation	9	3.903	0.434	0.006		
Synthesis	9	2.870	0.319	0.019		
Source	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.159	2	0.079	6.898	0.004	3.403
Within Groups	0.276	24	0.012			
Total	0.435	26				

Summary and ANOVA: HSU						
Groups	*Count*	*Sum*	*Mean*	*Variance*		
Analysis	25	4.067	0.163	0.008		
Evaluation	25	8.251	0.330	0.012		
Synthesis	25	12.683	0.507	0.021		
Source	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.485	2	0.743	54.814	0.000	3.124
Within Groups	0.975	72	0.014			
Total	2.460	74				

Table A-2.
Group-wise comparison of design activities types across each project.

Summary and ANOVA: Analysis						
Groups	Count	Sum	Mean	Variance		LSD - groups
AWM	24	5.188	0.216	0.002		A
GCD	16	0.696	0.043	0.008		
EAF	9	2.227	0.247	0.010		A
HSU	25	4.067	0.163	0.008		
Source	SS	df	MS	F	P-value	F crit
Between Groups	0.360	3	0.120	19.075	0.000	2.736
Within Groups	0.441	70	0.006			
Total	0.801	73				

Summary and ANOVA: Evaluation						
Groups	Count	Sum	Mean	Variance		LSD - groups
AWM	24	8.690	0.362	0.013		A
GCD	16	10.832	0.677	0.021		B
EAF	9	3.903	0.434	0.006		A B
HSU	25	8.251	0.330	0.012		A
Source	SS	df	MS	F	P-value	F crit
Between Groups	1.337	3	0.446	33.321	0.000	2.736
Within Groups	0.936	70	0.013			
Total	2.273	73				

Summary and ANOVA: Synthesis						
Groups	Count	Sum	Mean	Variance		LSD - groups
AWM	24	10.122	0.422	0.008		
GCD	16	4.472	0.279	0.012		A
EAF	9	2.870	0.319	0.019		A
HSU	25	12.683	0.507	0.021		
Source	SS	df	MS	F	P-value	F crit
Between Groups	0.587	3	0.196	13.584	0.000	2.736
Within Groups	1.008	70	0.014			
Total	1.594	73				

Table A-3.
Transition matrix of zero, first and second-order Markov process for case AWM.

zero-order Markov process

Actual of cell frequencies	A	E	S	Total
event 1	960	1424	1951	4335

Proportion of cell frequencies	A	E	S
event 1	0.22	0.33	0.45

first-order Markov process

Actual	event 2			
event 1	A	E	S	Total
A	0	107	150	257
E	124	0	167	291
S	172	193	0	365

Proportion	event 2		
event 1	A	E	S
A	0.00	0.12	0.16
E	0.14	0.00	0.18
S	0.19	0.21	0.00

second-order Markov process

Actual	event 3			
event 1-2	A	E	S	Total
A-A	0	0	0	0
A-E	22	0	25	47
A-S	30	21	0	51
E-A	0	26	30	56
E-E	0	0	0	0
E-S	15	14	0	29
S-A	0	24	56	80
S-E	15	0	36	51
S-S	0	0	0	0

Proportion	event 3		
event 1-2	A	E	S
A-A	0.00	0.00	0.00
A-E	0.07	0.00	0.08
A-S	0.10	0.07	0.00
E-A	0.00	0.08	0.10
E-E	0.00	0.00	0.00
E-S	0.05	0.04	0.00
S-A	0.00	0.08	0.18
S-E	0.05	0.00	0.11
S-S	0.00	0.00	0.00

Table A-4.
Transition matrix of zero, first and second-order Markov process for case GCD.

zero-order Markov process

Actual of cell frequencies	A	E	S	Total
event 1	536	850	791	2177

Proportion of cell frequencies	A	E	S
event 1	0.25	0.39	.36

first-order Markov process

Actual	event 2			
event 1	A	E	S	Total
A	6	124	65	195
E	106	67	124	297
S	90	140	6	236

Proportion	event 2		
event 1	A	E	S
A	0.01	0.17	0.09
E	0.15	0.09	0.17
S	0.12	0.19	0.01

second-order Markov process

Actual	event 3			
event 1-2	A	E	S	Total
A-A	0	2	1	3
A-E	20	17	15	52
A-S	14	15	1	30
E-A	1	34	14	49
E-E	9	0	14	23
E-S	9	39	0	48
S-A	1	23	23	47
S-E	13	25	47	85
S-S	3	0	0	3

Proportion	event 3		
event 1-2	A	E	S
A-A	0.00	0.01	0.00
A-E	0.06	0.05	0.04
A-S	0.04	0.04	0.00
E-A	0.00	0.10	0.04
E-E	0.03	0.00	0.04
E-S	0.03	0.11	0.00
S-A	0.00	0.07	0.07
S-E	0.04	0.07	0.14
S-S	0.01	0.00	0.00

Table A-5.
Transition matrix of zero, first and second-order Markov process for case EAF.

zero-order Markov process

Actual of cell frequencies	A	E	S	Total
event 1	582	931	772	2285

Proportion of cell frequencies	A	E	S
event 1	0.25	0.41	0.34

first-order Markov process

Actual	event 2			
event 1	A	E	S	Total
A	17	62	61	140
E	79	12	76	176
S	67	81	33	181

Proportion	event 2		
event 1	A	E	S
A	0.03	0.13	0.13
E	0.16	0.02	0.16
S	0.14	0.17	0.07

second-order Markov process

Actual	event 3			
event 1-2	A	E	S	Total
A-A	0	0	0	0
A-E	6	1	6	13
A-S	6	16	2	24
E-A	0	12	5	17
E-E	2	0	0	2
E-S	5	29	1	35
S-A	0	3	13	16
S-E	7	1	8	16
S-S	0	0	0	0

Proportion	event 3		
event 1-2	A	E	S
A-A	0.00	0.00	0.00
A-E	0.05	0.01	0.05
A-S	0.05	0.13	0.02
E-A	0.00	0.10	0.04
E-E	0.02	0.00	0.00
E-S	0.04	0.24	0.01
S-A	0.00	0.02	0.11
S-E	0.06	0.01	0.07
S-S	0.00	0.00	0.00

Table A-6.
Transition matrix of zero, first and second-order Markov process for case HSU.

zero-order Markov process

Actual of cell frequencies	A	E	S	Total
event 1	255	577	706	1538

Proportion of cell frequencies	A	E	S
event 1	0.17	0.38	0.46

first-order Markov process

Actual	event 2			
event 1	A	E	S	Total
A	20	22	31	73
E	32	23	30	85
S	32	39	7	78

Proportion	event 2		
event 1	A	E	S
A	0.08	0.09	0.13
E	0.14	0.10	0.13
S	0.14	0.17	0.03

second-order Markov process

Actual	event 3			
event 1-2	A	E	S	Total
A-A	0	0	0	0
A-E	4	3	2	9
A-S	3	1	1	5
E-A	2	8	8	18
E-E	1	0	0	1
E-S	1	4	0	5
S-A	1	2	4	7
S-E	4	1	6	11
S-S	4	0	0	4

Proportion	event 3		
event 1-2	A	E	S
A-A	0.00	0.00	0.00
A-E	0.07	0.05	0.03
A-S	0.05	0.02	0.02
E-A	0.03	0.13	0.13
E-E	0.02	0.00	0.00
E-S	0.02	0.07	0.00
S-A	0.02	0.03	0.07
S-E	0.07	0.02	0.10
S-S	0.07	0.00	0.00

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