RESOLVING ISSUES OF INFORMATION AND COMMUNICATION IN A BUILDING PROJECT

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ABSTRACT: An information and communication environment to support the building process was developed in collaboration with various partners from the Swiss building industry. The design of the environment was primarily guided by issues of information exchange in collaborative building projects raised by these partners. This paper aims to provide an in-depth discussion of these issues and present the way or ways the environment was developed to deal with them.

KEYWORDS: information exchange, communication, document management, collaboration

1. INTRODUCTION

A research team at the Chair for Architecture and CAAD, Swiss Federal Institute of Technology Zurich, has developed an information environment for the Swiss Architecture, Engineering, and Construction (AEC) industry (Schmitt *et al.*, 1999; Stouffs *et al.*, 1998). Funded by the Swiss National Science Foundation (April 1996 – December 1999), the team collaborated with other research groups (structural engineering and mechanics, artificial intelligence) at the Swiss Federal Institute of Technology Lausanne, two professional organizations of architects and engineers, and a number of small and medium-sized companies (in the areas of architecture, building engineering, steel construction, electrical contracting, facility management, and information technology) in the Swiss AEC industry. The goal of this research project was to provide a common technical platform for information, communication, and collaboration between all participants in the building planning, design, construction, and management processes (Lottaz *et al.*, 2000; Schmitt *et al.*, 1999).

The design of this ICC (Information, Communication, and Collaboration) environment was primarily guided by a number of issues concerning the exchange of information and access to this information among all participants in a building project. These issues were raised by the industry partners in a series of project meetings in which the developers' team presented consecutive versions of the environment to the partners and requested their feedback and comments. The issues brought forward reflect on time constraints and cost aspects that all too often restrict one's room for action in a building project, as well as on a desire to increase one's effectiveness and agility in these activities (Herbert, 1997; Preiss *et al.*, 1997). All partners acceded to the role Information and Communication Technology (ICT) can play in this process, though there was also a consensual worry that if in a team, all except one participant have access to such technology and experience in using it, the one without it may slow and possibly break the information flow.

The ICC environment is a Web-based publishing environment serving the development and dissemination of tools that support specific needs and processes. Founded on the Web, it imposes only minimal computing requirements on the participants, i.e., Internet access and

browser software. The adoption of a document-based approach averts the need for each and every team member to take part in a rigorous data collecting. Web-based publishing also enables an instant retrieval of all documents that are made available by the project participants, removing the need to maintain paper copies. With the support of a database and by referencing, rather than storing, the documents in the database, these can be maintained in a decentralized way and according to any electronic document system the participants have each already adopted. Through registration and authentication of the participants, the database also enables the imposition of access restrictions and ensures that authoring information is collected with each information entity. Finally, a plug-in system for extended functionalities allows the participants to adopt such functionalities when and where appropriate. The ICC environment currently offers plug-in applications for the distribution of project documents and reports within a team, for the management of discussions and decision making among the team members and, most importantly, for viewing, browsing, and retrieving information in a variety of ways.

Since the project was started there has been a lot of other developments in the area of Web-based project and document management applications, including commercial releases. Currently, a diverse selection of such tools is available in the market and has found its way into the AEC industry, especially in the US (Smith, 2000; Roe, 1999). Together, these tools offer the customer an extensive choice in features, support, price, and customization capabilities. Some of the more common features found in these tools, such as the ability to redline CAD drawings, are resolutely absent from the ICC environment. As a research project befits, the resulting system attempts to complement commercial offerings, presenting new ideas and novel solutions that meet specific needs of the project's industry partners.

In the sequel, I provide a more detailed discussion of the issues as raised by the project partners and present the way(s) the ICC environment was designed to deal with these issues.

2. INFORMATION EXCHANGE IN THE BUILDING PROCESS

Some of the issues and items presented here may seem to have a rather 'historical' character instead of expressing an obvious need. In the (almost) four years that the project has run, a steady stream of ICT advances, slowly trickling into the workplace, have altered the context dramatically. At the onset, the exchange of information through electronic channels, e.g., e-mail or the internet, was uncommon in the AEC industry, restricted to a few, sporadic exchanges (Almeida *et al.*, 1998). Both professional organizations involved in the project were developing visions of industry networks of a closed and private nature with an emphasis on services provided by the organization. Currently, however, e-mail is more widely available and used, and developments by the same organizations have coalesced and relocated to the Web, emphasizing a more open environment that may draw both members and non-members. Nonetheless, these same issues remain actual and significant if we aim to reach the entire community and provide each with the same opportunities independent of size, financial strength, or informatics expertise.

2.1 The decision making process

The first set of issues and the developments that lead from them relate to the decision making process, and the negotiation and exchange of information that supports it.

2.1.1 Time-critical exchange

The project partners first acknowledged the need for a time-critical exchange of information. Even electronic data was at that time commonly exchanged on floppy discs through traditional channels. Although the resulting loss of time can be accounted for in the planning, when problems unexpectedly arise causing additional exchanges, delays are inevitable. Such delays exacerbate time constraints already common in the building process. Therefore, exchanges through electronic channels lead to obvious benefits in time, even when only a few participants take part. Fast electronic exchanges can also entice participants to increase information exchange and communication. This, in turn, can lead to better informed participants, to more efficient communication, and to an improved decision making process. For example, frequent or last-minute design changes can be distributed instantaneously, ensuring that others can rely on the latest updates.

Although information, including documents, can easily and quickly be exchanged through e-mail, and is increasingly done so, most e-mail applications offer little or no support for document management. Organizing e-mails within a project for efficient retrievals is far from trivial; integrating information from e-mails into a document management system requires a fair amount of handling. Furthermore, when distributing project documents through e-mail, each and every recipient is required to store their own copies and perform their own management activities. Instead, a Web-based environment can provide centralized access to published information and documents, requiring only a Web browser for support. This access can complement any local document management system already in use (see also section 2.2.1). Furthermore, additional applications and functionalities can be developed and integrated within the environment.

As can be deduced from the flurry of activity in developing Web-based project management applications (Smith, 2000; Roe, 1999), the combination of a Web environment with a document modeling approach currently best facilitates a shift from traditional to electronic exchange. The ICC environment embraces such a document modeling approach, where the information entities in the resulting collaborative structure are defined by the documents submitted by the participants (figure 1). Each entity corresponds to a single document and its related information, including authoring information, a categorization with labels, and user-defined attributes. The formats for these documents are defined by the tools and applications that the participants adopt. Their exact formats do not necessarily have to be known to the environment; additional support for different formats may be provided by browser plug-ins or environment extensions.

Presenting the ICC environment to the project partners led to a promotion of the Web as a medium for information and communication. Though the partners were already considering or seeking ICT solutions for information exchange, the promotion catalyzed a shift to the Web leading to its adoption for their own communication, presentation, or development.

2.1.2 Decision-making

Savings in time almost always result in savings in cost as preliminary decisions based on partial information can lead to errors and costly modifications. For example, a steel constructor may be forced to start with the construction of steel beams in order to fulfill on a deadline, even though a final decision may not have been reached yet on the exact location or measurements of the holes for ventilation ducts. If the final decision does not assent to the assumptions made for construction, the error will be costly to the company.

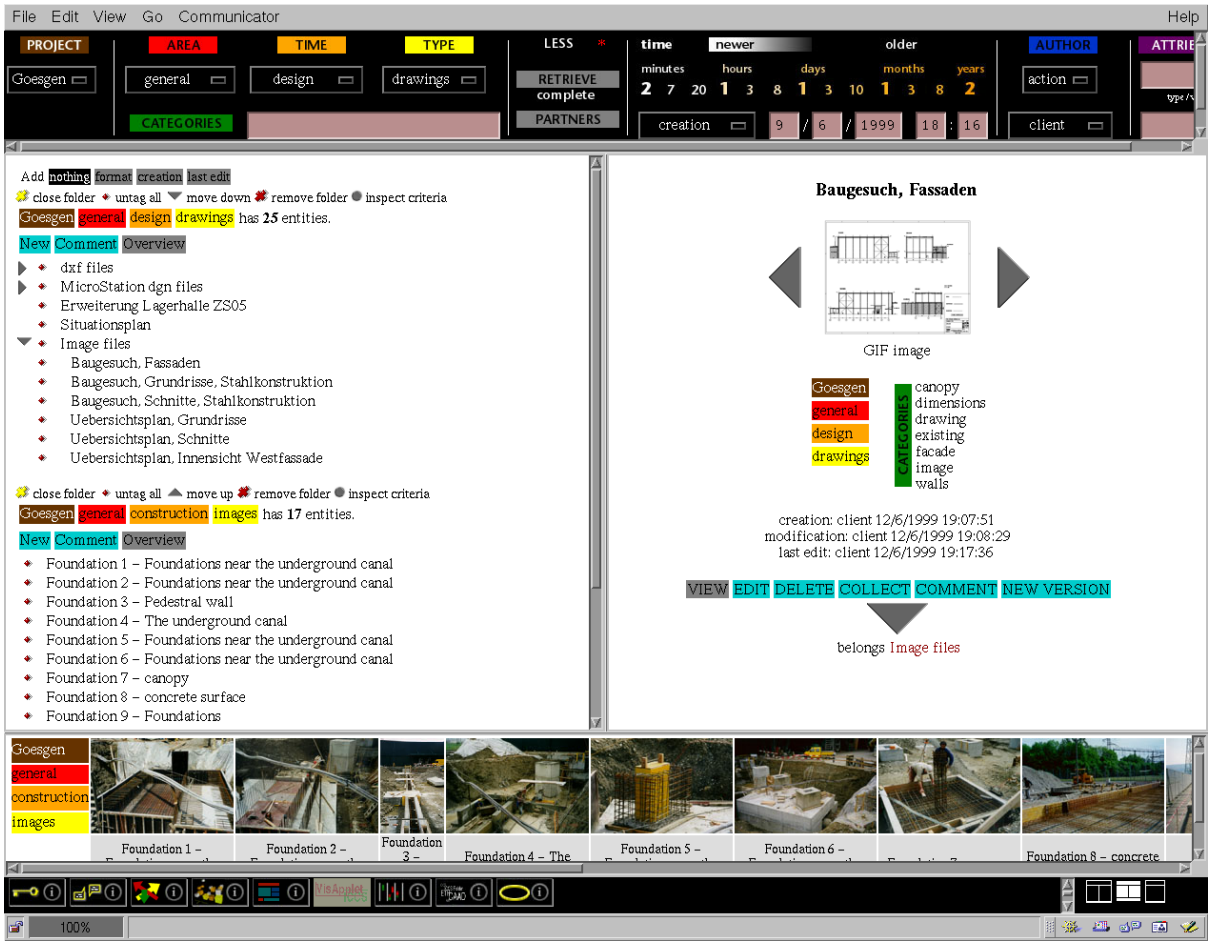

Figure 1. View of the ICC prototype interface. Bige Tunçer and Rudi Stouffs.

Decisions usually involve a number of iterations, especially when no obvious solution exists or conflicts arise between partial solutions. Moreover, changes in context, costs, requirements, deadlines, etc., often require a renegotiation of issues that had already been decided on. Organizational and informational constraints further complicate the decision making process. Adopting an electronic discussion forum and a supporting information system can mitigate the latter constraints towards a more effective and efficient process of negotiation and decision making. An electronic forum can intensify and accelerate negotiation and discussions without requiring physical meetings. When held in the confines of an information environment, the discussion can be enriched with references to published documents and information, clarifying statements and standpoints and leading to a better understanding of fellow points of views. Additionally, recording discussion and decisions for later referral and revisits can reduce subsequent renegotiation and information-loss.

The ICC environment includes a plug-in application to support discussions and decision making in a team (figure 2), storing both the subject of discussion and all contributions as documents within the information structure. It presents the user with an overview of all current discussions that involve the user, highlighting those that await a decision or standpoint from the user. Participants' responses as well as the final outcome are collected and attached to the subject entity and managed by the plug-in in order to determine a discussion's progress status. A document ascription facility for collaborative authors assigns both access rights and responsibilities to the parties involved. Authoring information credits individual contributions and affords feedback on the role of a participant in the collaborative process.

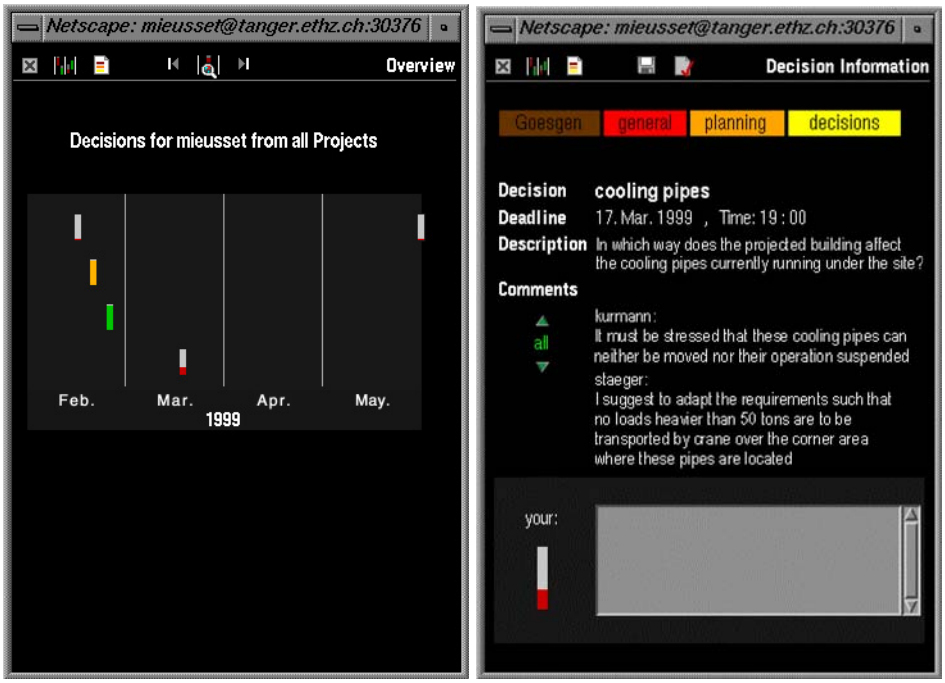

Figure 2. Decision support plug-in: overview (left) and view of a discussion status (right). Kuk Hwan Mieusset and Benjamin Stäger.

Early decisions can have a profound impact on issues surfacing at later moments in the building process. Such impact may not always be obvious, impeding an efficient handling of these issues and possibly involving a renegotiation of previous issues or decisions. Such a situation may be further aggravated as a result of participants retreating from the project at an early stage, requiring their tasks and responsibilities to be handed over to fellow or new participants. In this process, information related to the project's history that is not explicitly available in documents and reports is often lost. Discussions and negotiations frequently involve informal communication and rely on information that is not shared among all participants, while only the final result finds its way into the project's design or documentation. In the long run, however, the reasoning that led to the decision often has a stronger impact on the project than the actual result of this decision.

Another plug-in application attempts to resolve the problem of information-loss when a participant leaves the project by assisting this person in handing over responsibilities to fellow participants. The plug-in presents the user with a list of documents that he currently plays an active role in, suggesting for each document one or more alternative actors. Upon making a selection, the application then requests a confirmation from the designated participants. If the user desires, or no alternative is available, responsibility about a document can also be taken on by the system.

2.1.3 Negotiation

Many conflicts in traditional collaboration result from a disagreement over the values of parameters. Such disagreement usually stems from the practice of participants suggesting only single values for parameters. As a result, a negotiation may not converge to an acceptable solution for all partners, even though no real conflict exists. Instead, early decisions on single solutions invoke artificial conflicts that lead to needless negotiation, whether or not a solution actually exists. A better approach would be to determine and present ranges of possible values for parameters during negotiation. Such ranges can easily be specified in the form of mathematical constraints. By removing early decisions on values,

artificial conflicts are avoided. Furthermore, computational tools can be used to detect real conflicts at an early stage. When important requirements are expressed as mathematical constraints, constraint solvers can approximate the space for potential solutions, providing means to detect conflicts and guide negotiation (Lottaz *et al.*, 2000).

A project partner provided an example in the design of ventilation holes in steel beams. A conflict arose when the architect imposed the use of only two ducts for ventilation for reasons of cost, while the engineer restricted the size of the holes because of structural integrity, and the ventilation subcontractor required large ventilation capacity. Detecting the problem by hand may not be so easy. Instead, constraint solving techniques can detect such a situation very quickly, and when attempting to trace down the cause of the conflict, the structure of the Constraint Satisfaction Problem (CSP) can show hidden dependencies that, upon exploration, may lead to the discovery of conflicting goals (Lottaz *et al.*, 2000).

To support negotiation within the ICC environment, a plug-in was developed that links to a constraint solver for continuous CSPs (Lottaz *et al.*, 2000; 1999). Through this plug-in, the ICC environment provides for the management of design constraints and variables with related information (figure 3). Whilst these constraints and variables are considered textual information entities by the environment, they correspond one-to-one to design entities as recognized by the constraint solver. The resulting information space specifies an entity for each constraint and variable in the CSP, contains relations that link constraints and variables, and includes other documents, such as drawings, images, and textual information, that link to constraints and variables in order to define or explain them. Changes in the CSP are automatically forwarded to the ICC environment, and connections between both interfaces allow users to navigate the information space from the constraint solver, or explore the CSP from the ICC interface.

The industry doesn't seem ready yet to adopt constraint solvers on any large scale for expressing and exploring design requirements. However, the integration of a constraint solver within a project management environment, which can be called upon for specific, small cases may lower the threshold to its use. The combination of strict semantics as inherent to a constraint solver and a flexible framework for free-form documents as offered by a document management system can provide a synergetic compromise for an effective negotiation.

2.2 The information process

The second set of issues and solutions relate to the access to and the retrieval and distribution of information among the participants in the collaboration.

2.2.1 Access

Ideally, a Web-based project management application can be used to store and manage all documents and information generated in a building project. Practically, it is more likely that such a system will be used to complement participants' own electronic archiving systems, at least at the onset. Participants may be wary of placing all their documents in a shared workspace, even if access to these documents can be restricted. Given the currently limited bandwidth of the Internet, and the risk of Web server downtime, storing all documents on a centralized site may not be the most efficient solution either. Additionally, an initial phase in which participants familiarize themselves with the system and its functionalities, before they thrust themselves completely with it, is to be expected. As such, it is important that the system provides enough flexibility to the participants, allowing them to decide where to store

documents – without a need to duplicate activities – and how these documents are organized, even if the latter concerns a concerted decision by a number of participants.

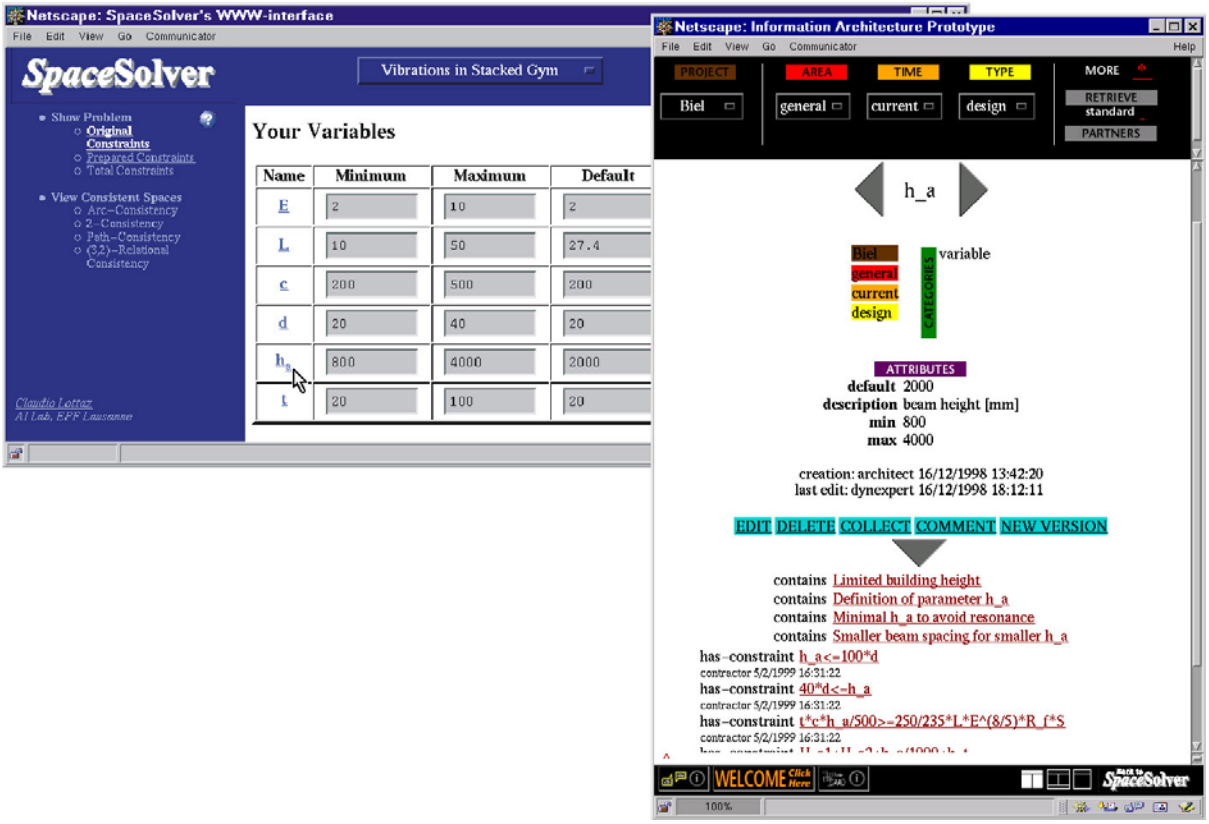

*Figure 3. Space*Solver *and ICC view of a simple constraint satisfaction problem. Claudio Lottaz and Rudi Stouffs.*

The ICC system does not include any central storage facilities. Instead, documents reside locally at the participants' sites (in HTTP-accessible directories) and are referenced in the database. As such, the participant can implement any physical file organization as suited, possibly according to an electronic document system already in use. Furthermore, the ICC system is developed as a distributed system with functionality from the central application server mirrored at local *webtop* servers. A webtop server additionally provides an upload facility within the local file system. Requiring only a simple web server and the Java Runtime Environment, such a webtop server can be installed by any participant locally.

Once stored and published, an organization of the information entities assists participants when searching, browsing, and managing project information. The ICC environment uses a classification of the information entities within a project according to three dimensions, similar to the CIP cube (Center for Integrated Planning; Arb *et al.*, 1997). Whereas the indices of the CIP cube are exactly defined (according to established practices in the Swiss AEC industry) the specification of these dimensions in the ICC environment is left to the project team in order to reflect on the specifics of the project and the anticipated processes. Documents can be submitted, selected, and visualized by project and with respect to this three-dimensional structure. A VRML visualization of this organizational structure provides a navigable overview of the project organization (figure 4).

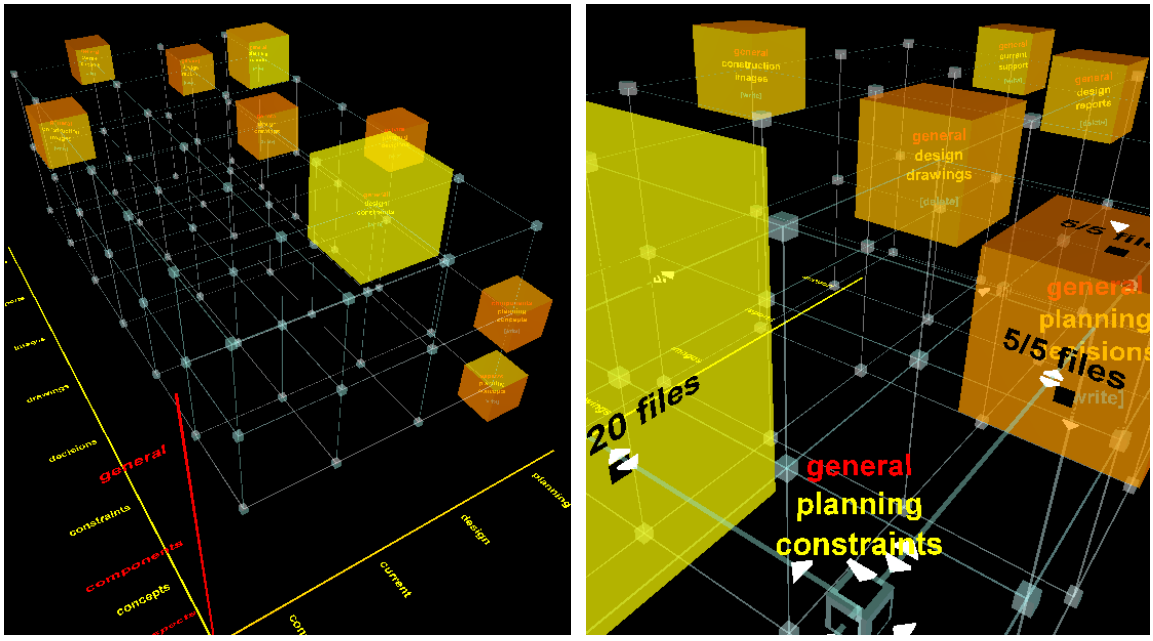

Figure 4. A 3-dimensional visualization of the organizational structure of a project. Component cubes are sized with respect to document count, and highlighted in the structure according to selected criteria, e.g., whether there are new documents or documents waiting attention. Each cube links to an overview of the relevant documents. Bige Tunçer.

2.2.2 Retrieval

In a struggle to become more agile, well-defined control hierarchies and relationships are making place for more intricate collaborative processes that are not as easily planned and controlled. Building collaborations are special in that both the project and the team, and as a result the processes, are potentially unique from project to project (Buckley *et al.*, 1998). This requires an increasingly networked thinking that brings partners to closer interaction but, without appropriate computational support, impedes the ease of overview and understanding. The information structures resulting from such collaborative processes are quite complex: these are multi-dimensional and highly related, although loosely structured. Methodologies of viewing document structures in the form of hierarchies, lists, hyperlinked documents, or tables increasingly illustrate the limitations of such presentations. Instead, an advanced representation that captures the information structures built during collaboration, combined with appropriate visualizations of these structures, can empower the partners in the analysis and understanding of the collaborative processes and increase their effectiveness during collaboration.

An information structure is visualized from the information entities and the corresponding links between these entities. Links allow the user to express relationships, browse the data space, and can assist in interpreting the information space. A measure of density, as expressed by the number of links that connect to an entity, especially in combination with time information, can also lead to the recognition of activity centers. Relationships can be defined explicitly in the information structure or recognized using data mining techniques. Such virtual relationships can connect information entities that are otherwise not obviously related. This connectivity enables users to broaden their views beyond the immediate context of recent activities in time and scope. Explicit and virtual relations can serve as attractors for the positioning of information entities. Further control can be provided through selective visualization and a characterization of the entities and relationships using weights. Size,

color, intensity, or transparency can all be used to express a component's weight; a terminological control may serve the user to specify these weights (Engeli, 1998).

An ICC plug-in offers a dynamic visualization of a document hierarchy (figure 5). Document titles are positioned with respect to a number of attractors, reflecting on both explicit and virtual relations. The interface allows the user to define, select, position, and resize different attractors in a single window. The document titles oscillate about their equilibrium positions, so as to facilitate the recognition of individual titles within local clusters.

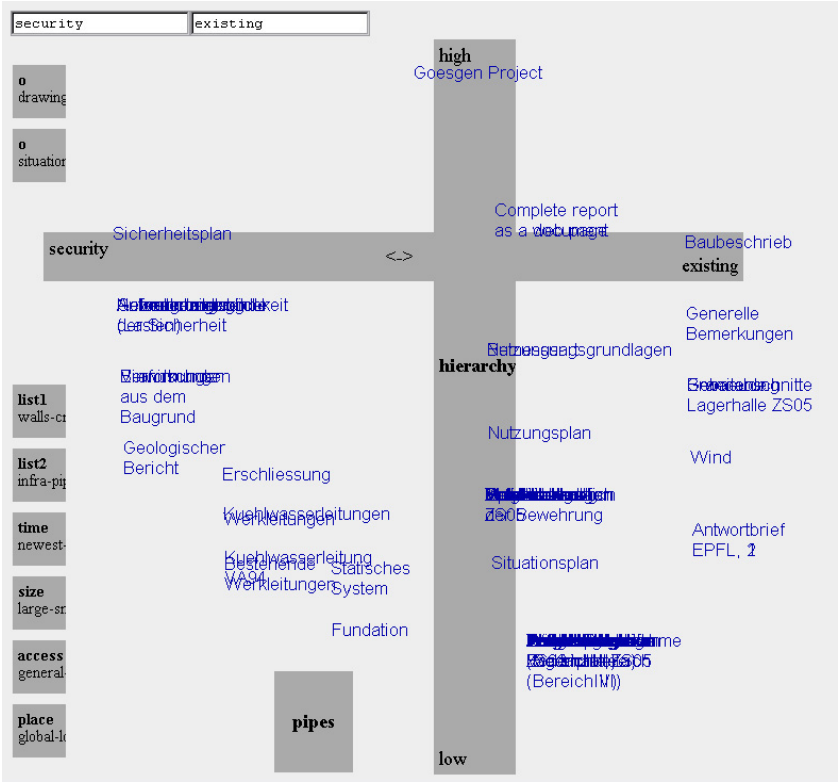

Figure 5. Snapshot of a dynamic visualization of a document hierarchy using attractors. Specifying a single category ('pipes') or a set of categories attracts documents that share one or more of these categories. Placing two categories in opposition ('security <-> existing') pulls documents to either end of the attractor corresponding to their categories. A third attractor is based on explicit grouping relations ('high hierarchy low'). David Kurmann.

Effective visualizations should enable a more effective and efficient collaboration among the participants through a visual analysis of the information structure and the underlying collaborative processes. In particular, these can serve to guide the user to zones or nodes of interest, highlight problems or issues that need consideration, determine activity centers, and illustrate complex processes.

2.2.3 Distribution

The project partners acknowledged the benefit of giving all participants continuous access to pertinent documents, reducing the need for mailing updates and reports as they become available. One engineering partner disclosed that on a large construction project involving a variety of companies, authorities, and organizations, one single person was kept busy all week long copying and mailing about 50.000 pages of letters and reports to the different parties. Since access to the Web has become almost omnipresent, adopting the ICC system or

a similar application for distributing information could save one person a tedious job and improve the time it takes to keep everybody up to date.

In this respect, the plug-in application that assists in the generation and distribution of project reports was most appreciated. Commonly, status reports are periodically required in order to inform all involved of advances or delays with respect to the intended progress. Such a report generally includes project status information and information about recent documents, information that should already be present in the environment. Using dynamic HTML, this application enables the user to specify the pieces of information to be included, then lay them out on a web page, and subsequently store the layout together with the names of the addressees. Upon reception, an addressee can either print the document or read it on the screen, and subsequently remove his name from the list to acknowledge receipt.

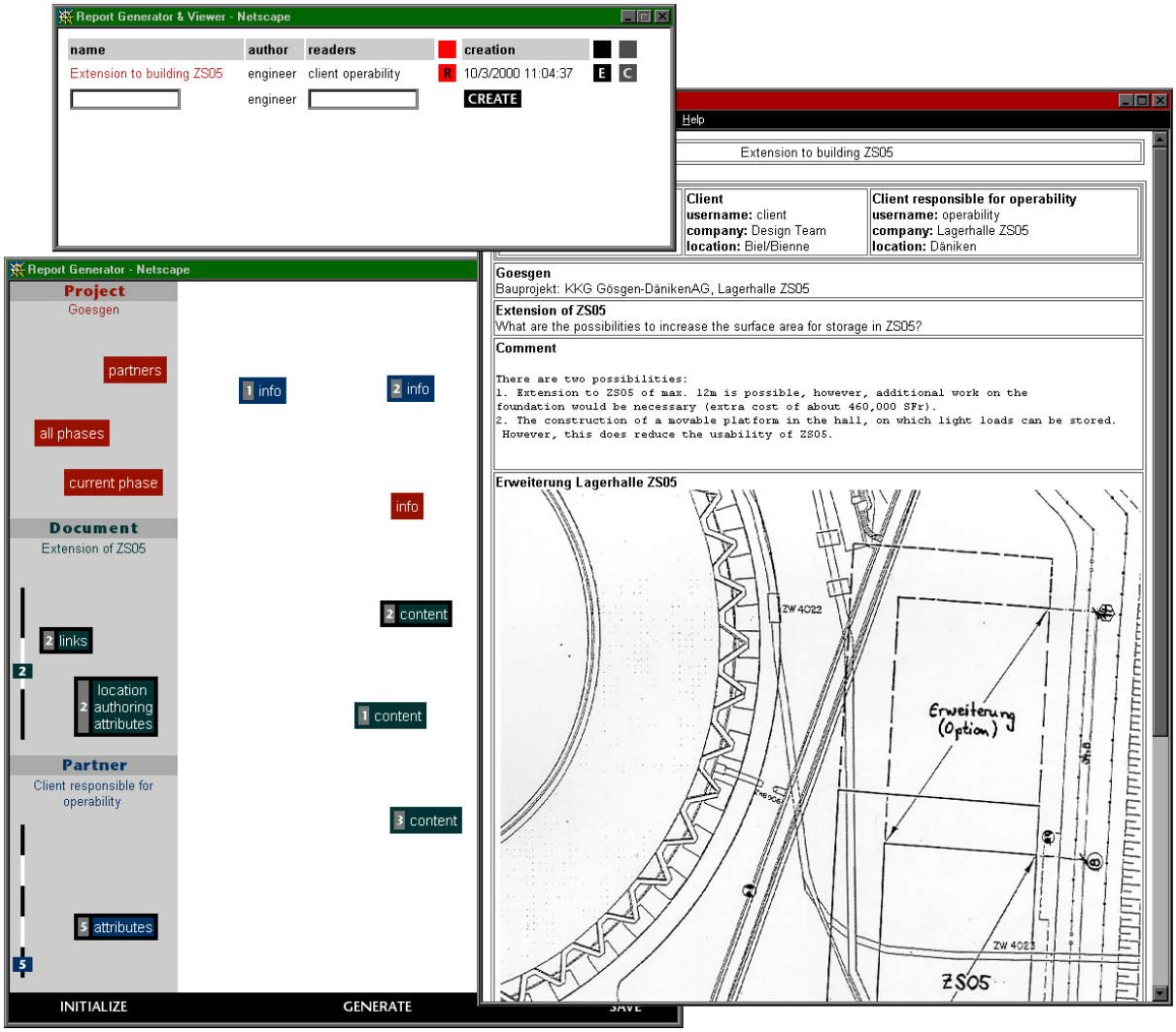

Figure 6. Report created with the report generator application: left below, the layout specification; right, the resulting report; above, the reports overview. Bige Tunçer.

Once information and documents are collected electronically, many related activities can gain an efficiency that previously might be unthought of. Reports can easily be assembled from the available information. Public relations could be supported by preparing printed or electronic publications, e.g., web sites. Information can be reused at a later stage or in a subsequent project. As the Web clearly shows, the hunger for information is insatiable. As

project participants will become accustomed to a better access to information, so will their needs for additional information increase. This swelling flow of information among participants also introduces new problems and concerns. Can information still be attributed to a particular person or group? Is the information owned by the author(s) or by the project team? Can information be made available outside of the project or reused in a subsequent project? If the current trend on the Web is anything to go by, the value of information will decrease as the supply grows. Value will shift from being a property of the information itself to being a property of the provider, i.e., information will become almost worthless once it is public. The answer to the questions above will depend strongly on whether this evolution persists.

3. CONCLUSION

Though presumably distorted by the selection of partners interested in the project, it was evident that the lack of experience in ICT was not due to any aversion but rather to the nature of the industry. On the one hand, it is largely fragmented into small and medium-sized companies that are active in a wide variety of knowledge domains and are not part of any strong organizational structure(s). As a result, there are few forces urging companies to adopt new information technologies, or to ensure compatibility between adopted systems and approaches. On the other hand, the industry is characterized by a diversity in products and processes to the extent that building collaborations are potentially unique from project to project. This not only makes it harder to develop ICT that will assist each and every one, but also makes it less clear as to the advantages such technology may offer in different situations. As a result of these, even as companies are reminded of the needs for ICT in order to increase their efficiency and agility, time and money are lacking for adopting or even experimenting with new technologies, unless the effects and advantages are well understood beforehand.

The project's industry partners were very enthusiastic about the ICC environment and its adoption into practice. At the same time, the fragmented and conservative nature of the AEC industry (in Switzerland) formed a serious obstacle to any practical use. The very essence of the environment, its support for collaboration, proved to be a hindrance to its adoption at the same time. Although the environment has been designed from the very onset keeping in mind that not all collaborative partners may choose to participate, the environment's success still hinges on a concerted adoption by a number of partners. Furthermore, time constraints and delays that are all too common in construction projects obstruct the learning and adoption of new technology.

Nevertheless, the adoption of such an environment, even if used only for data sharing and information gathering, yields clear advantages in time and information access. Time constraints and a lack of information can lead to errors and higher costs: a time constraint may impose the start of an activity before the necessary approval or other related information has arrived. Instead, electronic data sharing gives partners instantaneous access to published information.

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