

Digital Environments for Learning and Collaboration Architecture, Communication, Creativity

Maia Engeli and **Andre Mueller**

Architecture & CAAD, ETH Zurich, Switzerland

Digital networks are gaining importance as environments for learning and creative collaboration. Technical achievements, software enhancements, and a growing number of applicable principles make it possible to compile complex environments that satisfy many aspects necessary for creative collaboration.

This paper focuses on three issues: the architecture of collaborative environments, communication in these environments and the processes inherent to creative collaboration. The information architecture of digital environments looks different from physical architecture, mainly because the material that it is made out of is information and not stone, wood or metal and the goal is to provide appropriate paths and views to information. Nonetheless, many analogies can be drawn between information architecture and physical architecture, including the need for useability, aesthetics, and consistency. To communicate is important for creative collaboration. Digital networks request and enable new strategies for communicating. Regarding the collaborative creative process we have been able to detect principles and features that enhance this process, but there are still many unanswered questions. For example, the environment can enable and improve the frequency of surprise and coincidence, two factors that often play decisive roles in the creative processes but cannot be planned for in advance. Freedom and transparency within the environment are other important factors that foster creative collaboration.

The following findings are based on numerous courses, which we have taught using networked environments and some associated, research projects that helped to verify their applicability for architectural practice.

Introduction

Digital networks can enable and enhance creative collaboration on design tasks. Just as network support enables and expedites worldwide collaborations, other forms of collaboration can profit from an enhanced set of tools, new capabilities, and computer-supported processes. Technical innovation steadily confronts us with more user-friendly tools for communication, the exchange of data, and the storing and access of information. Nonetheless, it is important to consider the role of the individual within an environment that seems to be dominated by technology. Motivation, transparency, and user-support are all-important aspects for enhancing networked digital environments beyond basic technical capabilities.

In this paper, we are focusing on the architecture of environments for collaboration and communication and the question of collaborative creative processes. These findings are based on our experiences in creating and applying networked environments for courses in "Architecture and Information Technology" and "Virtual Design Studios". Since 1995, 17 courses were held and six different approaches were implemented. Much of this experience was further explored in research projects for the AEC (architecture, engineering, and construction) industry as well as in knowledge management.

Our findings will be illustrated with examples from the three courses "Information Landscape", "Phase(x)" and "fake.space":

Information landscape

In this first year Information Technology course, 200 students collaborated to create a two-dimensional visual landscape with landmarks leading to carefully selected "information-bytes" on architecture, art, and philosophy. The students worked in teams of two. Each team could design one rectangular area of the whole landscape, the goal being to design a landscape together with seamless transitions between the individual contributions. This required that the students exchanged ideas with their neighbours and negotiated common design strategies. The basic landscape evolved over a period of three



Figure 1: A strip of the landscape showing the "Yellow Ribbon" that evolved over time and became the landmark for links to 5000 years of architectural history.

weeks. In the next exercises the students searched for valuable and appealing information on the World Wide Web as a springboard to creating landmarks and links in the landscape. In this course the students experienced to work as part of a system towards a common goal even though the individuals could only influence the design in very small part of the whole.

Phase(x)

The purpose of the Phase(x) elective course was to teach principals of computer-aided architectural design. The course was organized in different phases, each one with a specific theme and an associated exercise. By participating in this course students became authors in a network-oriented process which although administered by a system, depends on the content provided by the participants. The rule enforced by the system was that in each phase every student had to select a result by another student from the previous phase as a basis for the next task. This was made possible by allowing access to models deposited in a common database; there they could be seen and checked out by other students. The students had to be careful and critical in their selection in order to progressively enhance potentially genius ideas with each phase. This setup required them to examine carefully the different results, thereby confronting them with the whole creativity produced in a collaborating community.

Phase(x) was first implemented in Fall 1996. The

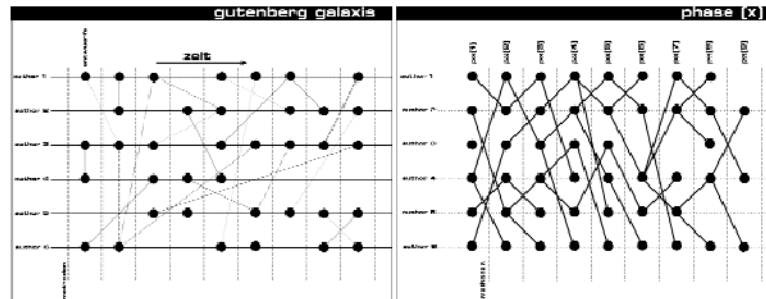


Figure 2: The "Gutenberg" scheme versus the Phase(x) scheme. Illustration: Florian Wenz.

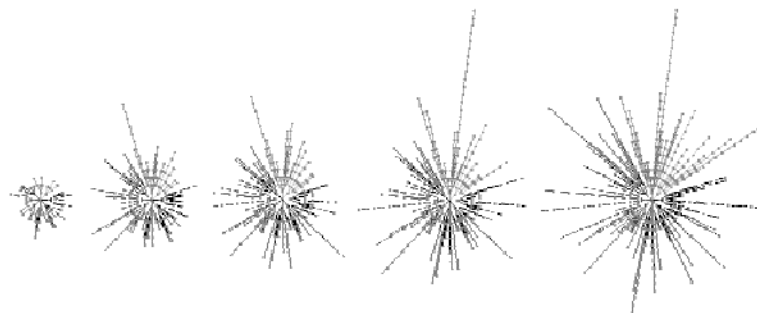


Figure 3: The growth of the fake.space system. Illustration Urs Hirschberg, Implementation Fabio Gramazio.

scheme has also been used in internationally coordinated Virtual Design Studios (see Kolarevic et al., 1998). It has also been adopted by other universities for CAAD teaching as well as in other fields.

fake.space

In this elective course the theme of space was explored. The name fake.space is intentionally both provocative and programmatic. It is a multi-authored multi-threaded narrative about space, or rather about faked space, that is virtual, simulated, make-believe, falsified, imagined space. (Hirschberg, 1998). fake.space consists of individual nodes growing outwardly from a central connector node to collaboratively explore eight space-related themes. The students added images, 3D models and texts into the system. The environment was designed to provide many paths to the data, allowing for various different kinds of views to the whole as well as to

individual nodes, thereby achieving a high degree of transparency among the contributions.

Architectural issues of digital environments

In the future, the majority of people will collaborate in networked environments and the design of such environments will gain in importance. In turn, the environments will be judged by how efficiently they support the work at hand, enhancing the working environment with appropriate concepts and efficient technologies.

The growing complexity of collaboration possibilities in digital networks turns the design of elaborate digital environments into an architectural task with the goal of producing functional, aesthetically-fulfilling, robust and rich environments able to support social interaction.

Since the architecture of the digital realm is made out of information, instead of stone, plaster, wood or metal, there is actually no need for metaphors from the physical world as is often seen in "virtual campuses"¹. Such simulations slow down the work process with needless information, distract from the main issue at hand and occupy valuable screen space. A well-described example can be found in Tufte's comparison of the design of two electronic guides to museums. He states that "In an architecture of content the information becomes the interface." (Tufte, 1997:146) To discover the issues this information architecture will have to focus on, it helps to think about situations where people have to work efficiently with information; i.e.: the daily experience of brokers, journalists, lawyers, insurance specialists, sales personnel, CEOs, researchers, or architects. It is interesting to note that "virtual malls or shops" rarely use metaphorical simulations. Maybe it is just pragmatic design, because images and 3D models take too much time to download and too much computing power to display. These examples also prove that comprehensive indices and search functions succeed in helping clients to find products they will buy. The Amazon Online Bookstore (<http://www.amazon.com>) is a perfect example to illustrate this aspect. It does not look like a physical bookstore but "takes advantage of the new platform and the new tools to change shopping itself" (Bayers, 1999). Moreover, in 5 years it grew to a 22.1 billion-dollar enterprise.

Nonetheless, information architecture, like other forms of architecture, has to fulfil both high functional as well as aesthetical expectations. Vitruvius identified "Utilitas, Firmitas and Venustas" (useability, consistency and aesthetics) as the three most important qualities of architecture (Vitruvius, 1591). These aspects also hold true for information architecture. Quoting from the introduction to the book *Information Architects*: "An information architect is 1) the individual who organizes the patterns inherent in data, making the complex clear. 2) a person who creates the structure or map of information which allows others to find their personal path to knowledge. 3) the emerging 21st century professional occupation addressing the needs of the age focused upon clarity, human understand-

ing and the science of the organization of information" (Wurman, 1996). In other words, although information architecture does not resemble physical architecture, there is a formal language and representation evolving for it.

Even though computing power is doubling every 18 months and fibre cables enhance network speed and new compression algorithms, the actual bottleneck is the display screen real estate. The standard 1024x876 or 1280x1024 pixel screens are very small windows onto the digital universe. Dealing with such a small display area is the major architectural challenge in the design of rich and complex environments.

A networked environment for collaboration has two roles: It is the virtual workplace for people and the container for the work that is produced. The relationship between data and authors leads to the functional need to organize complex interrelations into one coherent digital environment. To this end, the following aspects have to be carefully considered:

Information: In a collaborative process the authors create a lot of data. From this data as many facts as possible have to be gathered by the system. Not only the process directly leading to a result may be of use to the working environment, but also information about when a contribution was added, by whom, based on which knowledge, or with which goal in mind. Most of this additional information can be collected seamlessly by the system, by tracking accessible factors like time, author, machine, and data format. For this paper, we are focusing on the usefulness of such information, but the question of privacy will also need to be considered when collecting and revealing information belonging to personal contributions.

Relations: Data, mainly the sum of the contributions of different authors, may become more valuable if the relations between the different bits of information are legible. These can be relations in time, in space, about the authorship, or of topological nature. They basically help us to reason out why a certain bit of information was added, allowing us to better estimate its

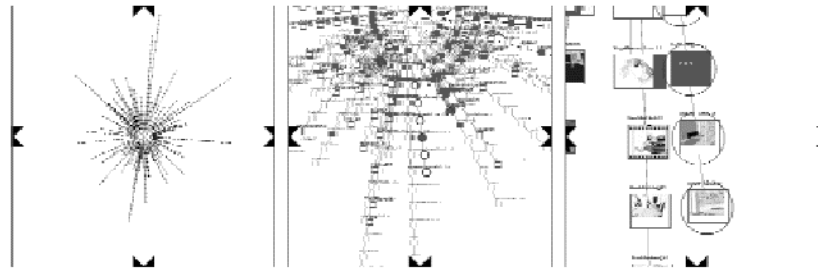


Figure 4. fake.space views, zooming from the system overview to individual contributions. Implementation: Fabio Gramazio.

value.

Context: The relations implicitly attached to the information work in combination with the individual perceptions of the user from the context. The individual users will access and read information in different ways, thereby creating a personal perception of the information space he/she is working in.

Processes: Changes of information, relation, and context over time are perceived as processes. The computer allows for the tracking and visualization of these changes - a powerful quality, since the reasoning within a creative process should be a continuation of previous events. The better the processes can be accessed, the more well-grounded are the decisions that are made. In addition, understanding the process allows for the re-use of contributions in a new context, thereby avoiding the inefficient re-inventing of solutions. Processes indicate how to continue the work at hand. They may lead to a clear goal or they may be open-ended. In any case they represent the creative dynamics within a system and certainly have a motivating effect. Making processes visible helps authors to create and place appropriate contributions throughout the collaborative creative process.

Views: Relations, context, and processes have to be made visible. Of the different ways to look at information, three categories can be identified: 1) Individual views focus on one's own contributions or the contributions of another author. 2) Work- or product-oriented views focus on progress and the result. 3) System-oriented views show overviews of data, relations, processes,

and participants. The internal representation of data in the computer and the way it is shown to the user are not the same, the functions which create different views can be regarded as the mediators between machine and user.

Interaction: The success of an environment is perceived by the ease of use and measured by the efficiency of work it enables. Therefore the interaction within the system, like the navigation through information, the perception of relationships, the readability of a context, the access to different views, the manipulation of data, and the submission of information, has to be optimized and comfortable.

To enable and combine these aspects in a digital environment is the main task for the information architect. The design has to regard the dynamic change of information and the continuous motion of the user through the information.

The following examples from our courses will illustrate how viewing structures inherent in the data and collected throughout the process can enhance the readability and the transparency of the digital environment. The significance of these views lies in how they combine data-processing by the machine with its interpretation by human intelligence. The computer can actually generate graphs of high semantic content without any knowledge of the meaning of these representations for humans. It is the responsibility of the designer and programmer to let the machine produce expressive views and allow for an optimized combination of computing and human capabilities.

Structures like fake.space (Fig. 4) supported the exploration of a theme by building up narrative structures. The different authors carefully chose the location for their contribution so that the expanding structure could be read outwards starting from the central node. This view shows a very open-ended process most suitable for the exploration of a specific topic, the analysis of a situation before starting the actual design process, or a collective "mind-mapping" process when searching for innovative solutions.

phase(x) (Fig. 5) focuses on showing the influences of the individual collaborators in the "memetic" process. The term "meme" was first introduced by Richard Dawkins in 1976 (Dawkins 1976). In analogy to genes, which allow for the replication of life, the meme is, in Dawkins' theory, the basis of cultural replication processes.

Information Landscape (Fig. 6) makes use of human mnemonic abilities. In a collaborative design process a two-dimensional landscape is formed. Different-looking landmarks lead to specifically selected information. Intelligently designed and sensibly located connections allow the user to remember which kind of information a specific landmark led to. The more one visits linked information, the richer the landscape becomes. The information landscape acts similarly to how a map can recall memories of a known place; but it also provides access to the actual linked information, so that one's memories can be refreshed and enhanced. The overall quality of this landscape becomes a combination of the quality of visual design and the quality of the information that is connected to it.

Communication

Communication is important to enhance collaboration on tasks within the virtual community. Communication can help to clarify, inform, support and motivate the collaborators, but most importantly it introduces the possibility for social interaction among the participants. This social aspect enhances the sense of identity of people that spend an increasing amount of their time online. Even though Turkle doubts that "to sit alone in rooms, typing at our networked computers and filling our lives with virtual friends will

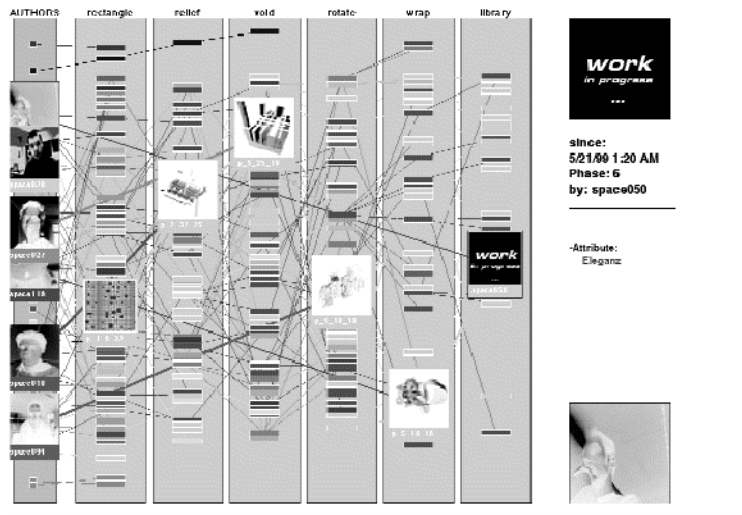


Figure 5: phase(x) , system and process are identical, the view shows the process - after each phase the authors had to chose somebody else's work to build on - one work and the different phase are highlighted. Implementation: Fabio Gramazio.



Figure 6: Information Landscape - the visual landscape becomes the basis for links to relevant information.



Figure 7: fake.space view onto the individual contributions with the “-/+/” voting information in the upper left corner.
 Implementation: Maria Papanikolaou.



Figure 8: fake.space comments sorted by work and by author. Implementation: Maria Papanikolaou

reverse the social atomization", (Turkle, 1995:235) it will certainly help to strengthen the virtually collaborating community and improve their common achievements.

There are different challenges when trying to enhance communication in digital environments. Both questions of design and technical issues have to be solved, and the motivation for the authors to communicate has to be present. If communication is a cumbersome process with little direct feedback and no real purpose, it will not be used as often as would be desirable to enhance the virtual community. Identifying the different design stages helps to integrate communication effectively into an environment and a collaborative process.

Communication can be useful for requesting information, providing a forum for dialog, discussions, feedback, and criticism. Requesting specific information may be necessary regarding important issues of the product, the circumstances, the process, new tools or changes in the environment. The dialog during the process can regard discussions of challenging aspects, asking for help, proposing strategies, or demanding for a specific action from another author. Discussions among more than two authors can be enabled with blackboard systems. It is helpful to record the discussions and keep them online for some time because some statements may be important for later steps of the creative process. Feedback mechanisms are often used in virtual environments. Feedback can be implemented in very simple ways, such as in voting or judging. These possibilities are simple to operate and therefore useful when the feedback of a large number of people is desired. They are also easy to evaluate by the system. Feedback is very helpful for creative work since the quality of a contribution usually cannot be computed the judgement has to come from humans. Criticism can occur through the possibility of commenting on the contributions of others. This kind of communication is more cumbersome and there has to be a mechanism that makes sure that the addressee reads the message. In addition, philosophical aspects of privacy come into play here, because some comments may be of interest to

everybody, others may need to be kept on a secret level.

In architectural design tasks communication can happen visually as well as verbally. In the course "Information Landscape" the students had to coordinate their design intents with those of their neighbours (every group worked on one small rectangular patch of the whole landscape). In the first week of work only visual communication was possible; the students had to try to understand the concept of their neighbours by studying it on the visual level and by observing the process. In the following phase verbal communication through written messages was made possible. In addition to visual communication, it helped to clarify intentions and to talk about issues that were not visible, like the procedure to create a certain visual effect with the image-processing program.

The verbal communication was recorded in the environment and allowed for a number of interesting observations regarding content and use of language. "When we step through the screen into virtual communities, we reconstruct our identities on the other side of the looking glass." (Turkle, 1995:177). We observed a variety of attitudes in the use of language, some of which considered typical for online talk. The attitudes ranged from super-nice to flames, many of them with a theatrical, role-playing touch to them. The use of super-nice, highly formal language is an attitude that is usually taken to hide shyness or insecurity. Flaming, on the other hand, seemed to originate from cultural differences. Some German addressees interpreted the impulsiveness of French students as being harsh and unfriendly, which led to angry and senseless dialogs. We also observed that casual and private communications got mixed with task-related discussions. Themes were often related to the situation at school and the other work they had to do, but also the weather and new movies became themes for casual remarks. Such dialogs indicated an increased level of acceptance of the digital work environment.

Communication in digital environments works best, when there is a good reason to communi-

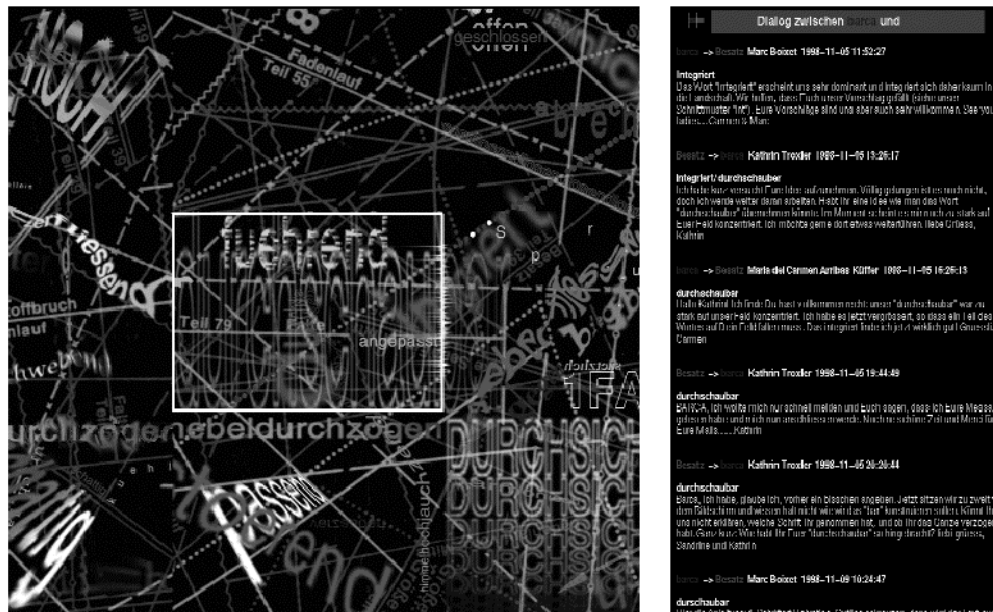


Figure 9: Information Landscape: Every author works on a small part of the landscape - communication with the neighbours on the visual and verbal level is very important.

cate like the participation in a common process, the collaborative design of a product or the collective exploration of a theme. Since communication with digital means is to the greater part restricted to written statements, there is high chance for misunderstanding. The availability of many channels (including videoconferences) and a clearly defined context for communication can reduce this danger.

To collectively engage in a design task means to share in a creative process and be confronted with ill-defined problems. Ill-defined problems are also found in economics, management, and other fields. Nowadays it stands for a general attitude of the savvy enterprise to consciously create a climate and a mechanism to motivate innovation in their market field through independent and creative collaboration. Digital collaborative environments play a central role in innovative processes in terms of connecting different people transparently in order to provide a great diversity of approaches and viewpoints. Furthermore they can visualise each element of interaction as specific as possible to sharpen

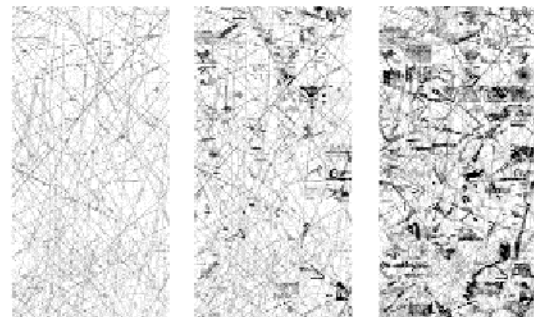


Figure 10: Different stages in the development of the information landscape.

and systematise thinking skills (Quinn, 1997: 148, 157-160).

Transparency and comprehensibility of the design process are important qualities for an environment for creative collaboration and are crucial aspects to the design of our course environments.

For example in the „Information Landscape“ environment, changes are automatically recorded on a daily basis. This allows the students to move back to particular points in time in order to understand the design decisions that were taken in the past. The students used this feature often as a basis for discussions. It helped to avoid redundancies in the process.

The digital environments for collaboration that we created in the last years were initially driven by qualitative as well as didactical aspects. Over time we became more and more aware of their social and creative implications. Such factors played an important role in creative performance. As a result, we started to pay more attention to the relationship between social-psychological factors and creativity as described by Teresa Amabile's Social Psychology of Creativity (Amabile, 1996). Among the social and environmental stimulants of creativity (Amabile, 1996:231-232) we can determine the ones that are most appropriate for digital collaborative environments.

Freedom to explore solutions is a precondition for creative work. Our digital environments are built to grow and change their overall quality depending on the contributions by students. They have a lot of freedom in deciding what to explore and how to accomplish the task. It is obvious that this freedom has certain constraints given by the digital environment and by the goals of the courses. Some restraints on the open-endedness of the tasks are even helpful to focus the creative efforts.

The ability to highly motivate people is another important aspect to enabling creative work. The motivation can stem from the desire to accomplish something important and to provide valuable contributions in the collaborative process. Therefore the transparency in the environment is of foremost importance, it has to be guaranteed that the contributions are seen. The students expect to get some kind of rewarding feedback. For example in phase(x) it is rewarding if many students chose one's result for the next phase. In "Information Landscape" one would like to be the initiator of a design idea that

spreads of a large area. In fake.space it is rewarding if other authors follow up a theme that one has introduced. The ability to collaborate with students from other universities, as in the Virtual Design Studio "Multiplying Time" (Kolarevic, 1998), can add to the motivation of the participants. Furthermore, to establish a common social sense helps to internalise the external motivation predetermined by course goals.

Individual attitudes toward the use of IT for designing and how individuals understand themselves in a broader social context gain a certain importance to be considered in the digital creative collaboration context (Chapman, 1997). We confronted this aspect in our digital environments by allowing the individual students to take a more or less public position at their own discretion through their work contributions and different means of self-representation. This possibility for self-expression as well as the collaborative setting helped to integrate individual attitudes toward the use of IT as reported by Chapman into the overall collaborative social context. Therefore, we focused our design efforts to support a collaborative community where creativity was strongly supported by an evaluation process that was work-focused and constructive.

We understand evaluations as an integral part of the communication in our environments. Amabile states that in order to support creativity, it is important that evaluations provide information about performance-improvement, or convey positive recognition of competence and valued work. It can be concluded that the positive effects of evaluations may be due to the motivational synergy mechanisms of external objectives in service of internal ones (Amabile, 1996:151).

Students learn from seeing each other's work. They are confronted with a large number of possible solutions for the same task, which add to their experience as designers and help them to draw from a larger background for their next creative task. These individual experiences and backgrounds enriched by the solutions out of

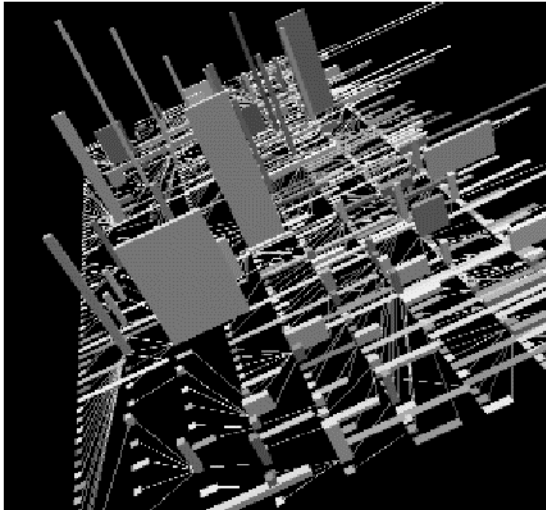


Figure 11: Phase(x) - A view showing the relationship between time and quality of the contributions represented by cubes, the higher the better, the longer, the more time was spent on the design. Implementation: Urs Hirsch-berg.

the collaborative process is considered by Collins as one of the three key elements for enhancing creativity (Collins, 1999: 307). The intersection of the three elements (domain-relevant-skill, creativity-relevant processes, and internalised task motivation) is most important for creativity.

Our digital environments are frameworks open to different forms of thinking and acts of creativity. The environments have a strong emphasis on the visual representation of information, because they are conceived principally for design related purposes. Moreover, they are conceived to support mixed-media contributions in order to address our different cognitive senses. For example text is often used to disambiguate or intentionally ambiguate the meaning of an image. Tufte described this as the qualities of visual parallelism and states that the perceiving mind has to actively work on them. (Tufte, 1997:79-82) This can also be understood as crucial qualities to the creative process itself. The work of the perceiving mind is a sort of game where new arrangements and connotations are produced. This game, which can be

understood as both an interpretative as well as a creative one, becomes much richer in collaborative settings.

We are not able to control all of the implications social interactions and environmental factors have on creativity. We often built successful opportunities into our environments that could only be evaluated after-wards. Interestingly enough, a well-designed environment can be very tolerant towards experiments. Features that do not work are not disturbing as long as there are ways to avoid them. This is important since unavoidable problems and incomprehensible components have a negative effect on the process.

In the future we will continue to focus on creative collaboration. New inputs are also expected from ongoing research on knowledge management as well as technological aids to enhance creativity as explored by Nickerson. He concludes his investigations with the questions: „Can we assume that such tools - at least the best of them - will facilitate creativity? And if so, will the facilitation be largely a matter of increasing creative output, or could it mean improved quality of output as well?“ (Nickerson, 1999: 421).

Conclusions

This paper focused on three aspects within digital environments: information architecture, communication, and collaborative creative processes. Other important issues focused on in earlier papers were motivation, transparency, and support (). With growing connection speed, computer screens, and computing power, digital environments will become more complex and their careful design will gain in importance.

Many of our empirical findings have been confirmed by those of specialists in other fields: Sherry Turkle shows numerous examples of people changing their attitudes and identities in the world behind the screen (Turkle, 1995). This seems to be a typical phenomenon, but it has not been confirmed whether or not it has a positive effect on creative work. Research on collaborative learning by Pierre Dillenbourgh leads

to the conclusion that collaboration has a lot to do with negotiation. (Dillenborough, 1996) In our environments, we observed that students like to communicate when they can negotiate common strategies, while the more general possibilities for communication were used much less frequently. Judith Donath's research on sociable media focuses on three areas: the visual representations of social phenomena, the role of information spaces as contexts for communication, and the presentation of self in the virtual world (Donath 1996). One can draw a strong analogy to the three views we distinguish in our environments: process views, overviews, and individual views and their effect on the community.

Work in appropriately designed digital environments can be a pleasure and the accessibility of the work of others enhances the overall performance of the class. We can make a direct comparison in this regard to an earlier version of the course taught without the support of a networked environment. (Wenz 1997)

In the near future, machine intelligence, better user-interface design and more reliable and faster technologies will enhance the digital environment. Simultaneously, new strategies are being developed to support collective creative processes. Some of these strategies will develop only in digital form, while others may be applicable to analog settings as well. Another important aspect is that people are feeling more and more at ease working on the computer, such that the computer can stimulate rather than inhibit creative work. Future networked environments can be envisioned as comfortable and intelligent places where the virtual team feels at ease and yet challenged to engage in the task at hand.

We expect a bright future for networked computers as a media for collaborating architects. Networked computers may allow for the generation of designs that go beyond those currently known. They offer this possibility through new methods for working and communicating.

Credits

Numerous people have contributed to the findings described in this paper. We want to thank them all, especially the students. They created fantastic work. Not only did they have the opportunity to work in specially designed environments, but they gave us valuable feedback for further enhancements. A part of the work was financed by a grant from the ETH Zurich. The following people have also participated in implementing and teaching the courses:

Information Landscape

(<http://alterego.arch.ethz.ch>):

Fabio Gramazio, Andreas Weder, Cristina Besomi, André Müller, Maria Papanikolaou, Patrick Sibenaler, Mischka Miskiewicz, Cornelia Quadri, Steffen Lemmerz, Tobias Friedrich, Rüdiger Kreiselmayr.

Phase(x) and fake.space

(<http://space.arch.ethz.ch>):

Prof. Gerhard Schmitt, Urs Hirschberg, Fabio Gramazio, Cristina Besomi, Florian Wenz, Maria Papanikolaou, Patrick Sibenaler, Mischka Miskiewicz, Benjamin Staeger, Bige Tuncer, Daniel von Lucius, David Kurmann.

References

- Amabile, T. M. (1996): *Creativity in Context, Update to The Social Psychology of Creativity*, Westview Press, Colorado.
- Bayers, Ch. (1999): The Inner Bezos, WIRED 7.03, March 1999, pp. 115.
- Chapman, G. et al. (1997): Creativity and the Computer Nerd: An Explanation of Attitudes. In Dawkins, R. (1976): *The Selfish Gene*, Oxford, Oxford University Press.
- Collins, M.A. et al. (1999): Motivation and Creativity. In Sternberg, R.J., Ed., *Handbook of Creativity*, Cambridge University Press, 297-312.
- Donath, J. (1996): *Inhabiting the virtual city: The design of social environments for electronic communities*, PhD Thesis, MIT Media Lab, Cambridge, MA.

Dillenbourg P., et al. (1995): The evolution of Research on Collaborative Learning, in Spada and Reimann (Eds.), *Learning in Humans and Machines*, Oxford, Pergamon Press.

Hirschberg U. (1997): Phase (x) - Memetic Engineering for Architecture. In proceedings of 15th ECAADE conference, Vienna, September 1997.

Kolarevic, B. et al (1998): An Experiment in Design Collaboration. In Seeböhm and van Wyk (Eds.), *ACADIA '98*, 90-99.

Nickerson, R.S. (1999): Enhancing Creativity. In Sternberg, R.J., Ed., *Handbook of Creativity*, Cambridge University Press, 392-430.

Quinn, J.B. et al. (1997): *Innovation explosion: Using Intellect and Software to Revolutionize Growth Strategies*, New York, The Free Press.

Tufte, E. (1997): *Visual Explanations*, Connecticut, Graphics Press.

Turkle, S. (1995): *Life on the Screen: Identity in the age of the Internet*, New York, NY, Simon & Schuster.

Vitruvius M. (1591): *De architectura Libri Decem* (The Ten Books on Architecture), Como, Italy.

Wenz F., Hirschberg U. (1998): Fake.Space - An Online CAAD Community and a Joint Enquiry into the Nature of Space. In *CAADRIA '98*, Osaka, Japan.

Wurman, R.S. (1996): Introduction to Information Architects, R. S. Wurman, Ed., *Information Architects*, Zurich, Switzerland, Graphics Press Corp.