Interactive Room Support for Complex and Distributed Design Projects

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Abstract: We are investigating the design of digital 3D interaction technology embedded in a physical environment. We take as point of departure complex, collaborative industrial design projects involving heterogeneous sets of documents, and physical as well as digital 3D models. The paper introduces our notion of interactive room technology supporting industrial design and describes two examples of this technology: the Designers' Workbench and the 3D Whiteboard, both integrated in a common distributed and collaborative infrastructure. The paper also describes a number of new easy-to-grab and lightweight interaction devices being experimented with in the interactive room environment. The interactive room technologies have all been designed with the requirement that they must seamlessly integrate both into the physical and into the digital work environment, while providing new affordances for industrial design work.

Keywords: CSCW, Interactive rooms, 3D Environments, interaction devices, design support

1 Introduction

The industrial design, engineering, and architecture domains present many interesting challenges for information technology support: heterogeneous sets of materials, need for bridging between physical and digital material, need for large displays of drawings and sketches, distributed collaboration support, etc. We have been engaged in projects (Büscher, et al., In Press; Büscher, et al., 1999; Grønbæk, et al., 1993) working with various open hypermedia (Grønbæk & Trigg, 1999), CVE (Büscher, et al., 2000) and 3D spatial hypermedia tools (Mogensen & Grønbæk, 2000) for these domains. These tools have up till now mainly been developed for the desktop computer environment. Inspired by recent developments in Cooperative Buildings (Fox, et al., 2000; Streitz, et al., 1998), Augmented Reality (Mackay, 1998; Rekimoto, 1997; Rekimoto & Saitoh, 1999), Digital Desks (Koike, et al., 2000; Wellner, 1993; Wellner, et al., 1993) and Medias-paces (Mackay, 1999), we have started development of what we call Interactive Room support for distributed collaborative design work. This paper describes these developments, the achievements so far as well as design issues for future development of these Interactive Room technologies. The paper is organized as follows: Section 2 gives a brief introduction to the application domain in general and some of the challenges it poses. Section 3 discusses the work in relation to research in the field. Section 4 describes the software infrastructure of the applications being utilized in the Interactive Room components. Section 5 describes a 3D whiteboard component. Section 6 describes the Designers' Workbench, which supports a seamless transition from use of 2D applications, over 2.5D to genuine 3D stereo visualization. Section 7 describes interaction devices and techniques. Section 8 concludes the paper.

2 Application domain

The application domains we have been working with so far are architecture, industrial design, and engineering. Empirical studies (Covi, et al., 1998), show that architectural and design projects often take place in open office spaces or dedicated project rooms, where 3-6 persons share some 20-40 m^2. Teams often consist of several small co-located groups who collaborate at a distance. The rooms are typically equipped with bulletin boards, whiteboards, paper-sketches, plans glued to the walls, samples on the floor, physical models on tables etc. In addition, desktop computer equipment is used.

Such environments serve a number of purposes: they create a shared awareness of status of tasks being worked on, they support mutual learning and motivation, as well as seamless transitions from individual to collaborative work.

This domain challenges the use of computers in many ways: computer displays including large screen projectors are insufficient to substitute for material glued to walls in that there is too little real estate to project information, and the monitors/projections are not as persistent as is paper. It is also hard to maintain a relationship between the physical samples and models kept in the room and the digital documents maintained in the computer. Finally, it is hard to support distributed collaboration in these settings because the visual and physical artefacts in the rooms are hard to share over a distance.

Not only are the materials being worked on very heterogeneous, the work settings in which they are used changes continuously as well. At one moment, one may be working alone on a CAD drawing, the next moment that drawing is one of the materials, along with sketches, briefs, and budgets, being discussed with a group of colleagues standing around a table or wall, and later it may well be the subject matter for a discussion with remote clients, partners, or subcontractors, now in a context of materials provided by these other parties.

This kind of work environment poses some challenges to potential computer support:

- Support for collaboration. In these domains, work is characterised by being highly cooperative. Groups of people are simultaneously accessing the same material, different people working on various parts of the whole, ongoing collaboration with clients and partners outside the office.
- Integration with standard software packages. As the work materials are continually under construction a separation between editing and presenting material (e.g. as in most web tools) will impose too much overhead.
- Fluent transitions between modes of work. There is a need to support the fluent transition from individual work, for example at a desktop, to collaborative discussion, using an electronic whiteboard, to remote collaboration via conferencing systems.
- Seamless transitions between physical and digital materials. In the domains, we are focusing on, the physical aspects of the products being designed cannot be disregarded. There is a need both to digitally enhance the physical objects as well as a need to 'physically enhance' the digital objects.
- Support for spatial organisation of heterogeneous material. In all the domains we are talking about here, to a large degree, work consists of creating and maintaining bodies of assembled material (concept sketches, texts with briefs, drawings with details, physical prototypes of the product, samples of material to be used, etc.). In work, these materials are constantly re-arranged in various spatial relationships.

The focus on architecture and industrial design does not imply that our technologies are bound to these domains. Various presentations, workshops, and discussions with other professions strongly indicate a much wider potential. However, we focused on participatory design (Büscher, et al., 2000; Büscher, et al., In Press; Bødker, et al., 2001) activities with architects and industrial designers.

3 Related Work

In this section we briefly discuss research related to what we call Interactive Room technologies that share characteristics with a number of areas, which will be briefly compared below.

3.1 Cooperative Buildings - I-Land

(Streitz, et al., 1998) describes both interactive walls and tables. The Dynawall is a large wall consisting of a number of coupled touch-sensitive displays. Applications allowing informal note taking and hypertext linking like (Streitz, et al., 1994) are supported. Moreover windows can be "pushed" from one end of the wall to the other, when more people are working in parallel on the wall.

The Interactable is a small table with a display in the middle allowing users to discuss documents retrieved directly on the table, and to enter notes etc. directly into a computer by means of the Interactable and a wireless keyboard. The Interactable supports similar functions as the Dynawall, and in addition it allows users to turn windows around such that people on the other side of the table can read the contents in the window.

3.2 Digital Whiteboards

A number of digital whiteboard applications have been developed during the recent 10-15 years (Moran, et al., 1997; Pedersen, et al., 1993; Rekimoto, 1998). These systems have taken advantage of a variety of pen-based and gesture based interaction techniques. Recently, (Rekimoto, 1998) has also experimented with the use of a palmtop computer as an interface to the Digital Whiteboard overcoming some of the problems of pen and gesture based interaction.

3.3 Digital Desks

Several digital desk and workbench systems have been implemented in recent years. They fall in two main categories: The first category is Augmented reality systems building bridges between digital information and paper-based information (Koike, et al., 2000; Wellner, 1993; Wellner, et al., 1993). The second category is virtual reality systems like the Responsive Workbench (Agrawala, et al., 1997; Cutler, et al., 1997) and the HoloBench (TAN Projektionstechnologie,) providing true stereo visualizations of 3D worlds, but little support for integration of digital or paper documents.

4 Interactive rooms

As our starting point for addressing the challenges mentioned above, we utilize the Manufaktur system developed within the Esprit LTR Desarte project (Büscher, et al., 2000; Büscher, et al., 1999). Manufaktur allows for manipulation and maintenance of relationships among materials in a 3D spatial environment. It

- integrates with standard applications,
- supports collaboration among clients on an intranet or the Internet, and it
- is running cross platform between Windows 2000 (95/98) and Linux on PCs, IRIX on SGI's, and Linux on PCs.

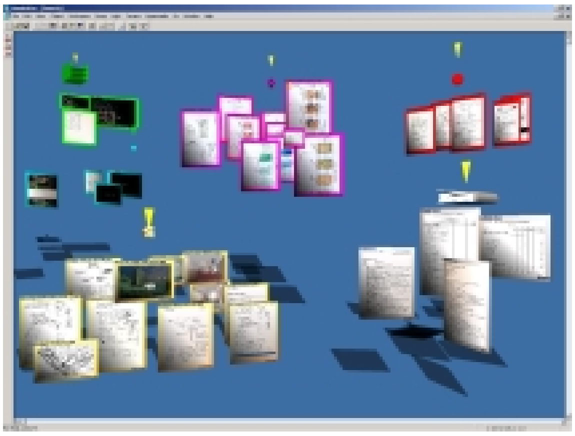

Figure 1: Desktop interface of Manufaktur

Figure 1 shows a prototype of a Windows 2000 Manufaktur client, developed for the desktop. It shows an open workspace containing a set of document objects. Double clicking any of the document objects will launch the document in its application, and changes to it will be reflected within Manufaktur in near real time. The objects can be sized, moved, rotated, etc; light effects may be applied; documents can be made (semi) transparent; organized into groups; and much more.

This paper focuses on Interactive Room aspects, details may be found in other papers, e.g. basic rationale in (Büscher, et al., 1999), hypermedia aspects in (Mogensen & Grønbæk, 2000) and cooperative virtual environment issues in (Büscher, et al., 2000).

In contrast to other examples of using 3D spaces for collaboration, e.g. (Carlsson & Hagsand, 1993; Greenhalgh & Benford, 1995), the focus here is on the materials being worked on rather than, for example, representing people. Likewise, we focus on supporting relatively known, heterogeneous, and not too large amounts of documents. For issues relating to cooperation in handling large amounts of uniform and relatively unknown data, see for example (Mariani & Rodden, 1999; Snowdon, et al., 1997).

In relation to the challenges described in the previous section, Manufaktur provides a promising starting point with regards to the collaboration support, integration with standard applications as well as the support for working with materials in a spatial environment. However, because it was designed for the desktop environment with keyboard and mouse as primary interaction devices, there are a lot of design issues involved in supporting the fluent transitions between work settings as well as transitions between the physical and the digital.

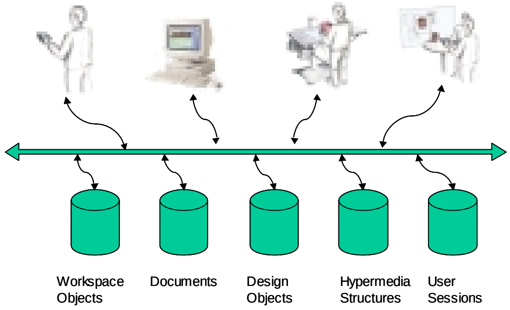

Figure 2: Generic architecture

What we are aiming at is depicted in Figure 2. The basic idea is to support the working on materials organised and manipulated in workspaces, but displayed and interacted with in different settings depending on the work situation at hand. For one person writing a letter, an ordinary desktop environment may be the perfect choice, for a group of people in a brainstorm, it may not. The work situations and settings indicated in the figure ranges from a group of people around an electronic whiteboard, to a couple of designers working on a 3D model on a table, to a single person working on details on a desktop, to the designer/architect on site via mobile internet on a laptop or a palmtop. The point is that essentially, they are working in the same workspaces, on the same documents and objects, only the display and interaction techniques differ.

In the following, we concentrate on elaborating the whiteboard and table as the desktop is well known, and the prototypes for the whiteboard and table are more mature than for the person with a mobile device on site.

The two prototypes being described are called the 3D Whiteboard and the Designers' Workbench, and they are running in the distributed collaborative infrastructure described and can thus immediately support both co-located and distributed collaboration on the same body of material.

5 3D Whiteboard

The ability to work with wall sized displays with more direct interaction than the mouse may be useful in a variety of situations, e.g. brainstorming, demonstration, education, sales, etc. In the following, we focus on situations with a group of people using the electronic whiteboard at the same time (brainstorm, design meeting, etc.).

At a conventional design meeting, notes and sketches are made on a shared whiteboard and people take notes. However, it often occurs that meeting participants wish to refer to documents and models from earlier projects, documents currently being worked on back in the office, the brief of the project, etc. Often a number of notes and sketches are made at the meeting, some of them important some not, and not recorded, since they were erased and not taken down in the minutes (Bødker, et al., 2001).

Figure 3: 3D whiteboard

One way of using the 3D whiteboard with Manufaktur in this setting is to set up a workspace for the meeting. In that workspace new documents, notes, scribbles, and objects may be created and worked on. Furthermore, if the need arises, one may insert references to existing workspaces that one is working on in other contexts than the meeting (provided a network connection and proper access rights). When a new workspace is inserted its documents and objects appear within the workspace being worked on and they can be referred to, spatially arranged, and manipulated. Likewise any documents 'born' in the meeting may be moved/-copied to existing workspaces. This way one may maintain an overview of a large body of material at once, at the same time as notes and sketches made during the meeting can be made persistent and spatially located close to existing related materials. With a voice connection (and probably video), the meeting may be distributed to a number of shared electronic whiteboards in various locations.

Currently, the 3D whiteboard is implemented through back-projection on large semi-transparent walls, and the interaction devices are extended with a Mimio (http://www.mimio.com/) and various prototypes of devices for both primary and secondary hand, (besides keyboard and mouse). Each user may have a 'pen' and they can all work at the same time, although one of the input devices tends to take precedence. Some of the issues being worked on at the moment include:

- The well-known problem that interfaces for desktops do not easily lend themselves to large screens, e.g. the menus, toolbars, etc. are too far away (Stewart, et al., 1999).
- A single pen lacks expressive power for manipulating objects in a 3D world, the pen gets 'overloaded' as the single interface for moving in three dimensions, rotating, accessing functionality, etc. The problem lies both in translating between 2D and 3D, and the ergonomic problem of having to press buttons (to provide modifiers) on a precision-device.
- To what degree and in what situations is it necessary, from the systems point of view, to be able to not only know what was done, but also who did it?

We are currently experimenting with various means to overcome these problems, including devices in the secondary hand, other means of tracking input than the Mimio (e.g. in order to be able to know the identity of the input device being used), and ways of bringing the functionality close to the user. These issues are expanded in more detail in section 7, following the discussion on working with the Designer's Workbench.

Compared to the Dynawall our whiteboard supports 3D instead of 2D workspaces and therefore does not require quite as much screen real estate. The Dynawall supports multiple users pointing at the same time, something that the whiteboard does not currently allow.

Compared to the digital whiteboard applications discussed above, our whiteboard supports: ready access to project documents on the Intranet or the

Internet, 3D spatial hypermedia organization of documents and 3D models, direct annotation and creation of new documents and 3D models. The whiteboard can be used as an ordinary 2D whiteboard and seamlessly move into a 3D mono interface allowing users to place documents and objects in the background, in clusters, on top of each other, etc.; creating more room for work while maintaining awareness of collaborative manipulation of other relevant documents and objects.

6 Designers' Workbench

The Designers' Workbench is a table with a projection surface, providing access to project folders and digital models like the 3D whiteboard. The Manufaktur system can be used directly on the table surface. Moreover, it supports a seamless transition to passive stereo visualization of digital models (requiring polarized glasses), such that digital models of design objects can be directly compared to physical models and previous versions placed on the table.

Our Designers' Workbench attempts to fill the gap between visualization systems and pure 2D digital desks in that it provides support for ordinary 2D documents and 3D models in the same integrated environment.

We view the Designers Workbench as a supplement to the Whiteboard in that it supports collaborative work on a mix of physical and digital models among a small group of people. The Workbench is also connected to other instances of Manufaktur (for example the 3D Whiteboard) and documents and digital workspaces may be shared interactively between Whiteboard and Workbench. Thus a discussion starting out at the Whiteboard may be continued in context at the Workbench and vice versa.

Figure 4 shows the first prototype of the Designers Workbench. The construction of the workbench allows passive stereo displays at the tabletop, using polarization to separate the two stereo images. The tabletop is made of glass with a dispersion coating that does not interfere with the polarization.

Two DLP projectors, based on digital mirror devices (DMD)[1], display the stereo images. In front of each projector is placed a polarization filter. Using active stereo display via shutter glasses was also explored, but current inexpensive LCD and DLP projectors do not provide for the higher than 120 Hz refresh rates that such a system requires.

To generate the stereo images for the workbench we use two PCs with 3D accelerators running Linux. Each PC runs the Manufaktur application in a special synchronized mode, such that one PC generates the image for the left eye and the other PC generates the image for the right eye. Currently the two PC's utilize the generic collaboration support and synchronize their displays across the 100 Mbps Ethernet using UDP with fairly good results. In the future we plan to use a single PC with two video outputs to better be able to achieve the necessary display synchronization.

Figure 4: Designers' Workbench

The Manufaktur application already supports head-tracked stereo on the HoloBench display device. In the future we may also add head tracking to the designers workbench although head tracking has proved to make displays quite unsuitable for more than one person to use at a time, because the image jumps and moves as the tracked person moves his head. Even though the lack of head tracking means that no person gets the perfect picture all the time, the stereo effect is good enough from a range of viewpoints that two or three persons can collaborate at the workbench using 3D stereo. (Agrawala, et al., 1997) gives examples of support for two-user head tracked stereo. However, this currently requires wired and relatively heavy shutter glasses.

As the computers driving the tabletop display are just ordinary PCs it is easy to use common desktop applications (on one of the PCs), while applying true stereo 3D is quite seamless. A designer can work in e.g., a word processor at one half of the tabletop display, and manipulate a 3D model in stereo at the other half at the same time.

Compared to the Interactable (Streitz, et al., 1998), our workbench supports interaction with conventional 2D applications with a pen or mouse interface, and in addition it supports a seamless transition

[1] Experiments show that LCD projectors cannot be used for this as they emit polarized light themselves.

to 3D stereo. The stereo visualization is currently only viewable from one side of the table, but when stereo mode is turned off, documents and other objects in the 3D environment can be rotated and turned in arbitrary ways, thus supporting roundtable discussion like the Interactable.

7 Interaction techniques

In this section we describe some of the new interaction techniques being experimented with on the 3D Whiteboard and the Designers Workbench. The aim of these devices is to be lightweight and support multiple collaborators and changing work situations. This requires a seamless integration with the everyday physical work environment. For example, using a glove for 3D interaction at the Workbench was deemed too cumbersome to use in everyday work situations where users walk to and from the Workbench frequently. Also, wired shutter glasses would inhibit the free movement of users between their desktop, the Whiteboard and the Workbench.

7.1 Laser pointer recognition

We have implemented experimental software for using a laser pointer to interact with Manufaktur running either at a wall or at the workbench tabletop. Using a video camera and simple image recognition software we track the red dot from the laser pointer, and use it to interact with Manufaktur. The laser can be used as a mouse to move objects around in a workspace. Work is also going on to implement gesture recognition to improve the laser-based interface.

The laser pointer interface is primarily aimed at groups collaborating in front of a live whiteboard. It lets participants arrange items on the whiteboard at a distance and thereby take a more active part in a discussion without getting out of their chair and going to the whiteboard.

The video tracking software can also be used to track the IR beam emitted from a cell phone or a palmtop computer. This will allow users to use their palmtop to point and select objects on the 3D whiteboard and invoke commands to bookmark or store them on the palmtop, for later presentation at a different physical location. This is an alternative to the pick-and-drop interface (Rekimoto, 1997) and it provides a workable implementation of the I-Land Passage idea (Streitz, et al., 1998).

7.2 Pointing and command devices

We have been using the Mimio pen interaction devices for early experiments with interaction techniques for table and whiteboard. But experiences have shown a number of limitations in this kind of interaction as described above:

1) The user needs a higher bandwidth interface to the applications than the limited “press/no-press plus 2D location” currently afforded.
2) We need to be able to track multiple users at the same time.

To handle the first problem we have made several experiments. The first experiment was to continue using the Mimio pen, and supplement it with a remodelled wireless mouse (see Figure 5). This Command device can be kept in the user’s secondary hand and be used to invoke commands.

Figure 5: FingerPen and Command device

Another alternative being developed is an extended Mimio like interface, where we can track two pointing devices at once. This has lead to the design of what we call FingerPens, which allow normal pointing with the forefinger and the middle finger to invoke commands on objects.

Both of these solutions are preliminary designs, and still require too much skill to manage precisely in longer lasting use sessions. But they both afford pointing and command invocation to the user in a more natural way than moving to a keyboard or a traditional mouse as is the case with the Mimio.

7.3 Grabbing device - Space Pincher

As the Designers Workbench provides stereo visualization of objects, it opens up the whole design space of 3D-interaction devices and two-handed input (Cutler, et al., 1997; Mapes & Moshell, 1995).

Figure 6: SpacePincher for manipulation in 3D

For a future version of our workbench we plan to use the SpacePincher (see Figure 6) idea proposed by (Gundersen, 1999).

All of the 3D interaction devices discussed in this section share the advantage that they are equally easy to pick and use as is a whiteboard pen or a pencil. This is useful for supporting co-located collaboration in an augmented reality environment.

8 Conclusions and Future Work

This paper has described developments of an integrated set of interactive room technologies supporting collaboration for architecture and industrial design. We have described a 3D Whiteboard as well as a Designers' Workbench.

The software support for our interactive room has taken the Manufaktur (Büscher, et al., 2000; Büscher, et al., 1999) as a starting point and extended it to support the workbench and the whiteboard and their interaction devices. The traditional desktop version of the Manufaktur has been field tested by designers, architects and landscape architects. The whiteboard and workbench has so far mainly been tested in co-located collaborative design sessions with industrial designers from a major Danish company.

Future work includes, among other things, to integrate media-space technology (Mackay, 1999) to feature synchronous communication between distributed interactive room settings. Issues here will be to find out whether video images should be integrated as objects in the 3D environment or they should be kept in separate windows or on separate displays. Another future work task is to build a bridge between physical design objects and digital models, like (Mackay, 1998) is proposing for paper and flight strips. In our setting we propose to tag physical design objects and link them to related documents that may show up on the Designers' Workbench when an object is placed on its surface.

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