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Virtual Video Prototyping

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Abstract

Computing power is an integrated part of our physical environment, and since our physical environment is three-dimensional, the virtual studio technology, with its unique potential for visualizing digital 3D objects and environments along with physical objects, offers an obvious path to pursue in order to envision future usage scenarios in the domain of pervasive computing. We label the work method virtual video prototyping, which grew out of a number of information systems design techniques along with approaches to visualization in the field of architecture and set design. We present a collection of virtual video prototyping cases and use them as the platform for a discussion, which pinpoint advantages and disadvantages of working with virtual video prototyping as a tool for communication, experimentation and reflection in the design process. Based on more than ten cases we have made the observations that virtual video prototypes 1) are a powerful medium of communication in development teams and for communication with industry partners and potential investors, 2) support both testing and generating ideas 3) are particular suited for addressing spatial issues and new ways of interacting. In addition practical use of virtual video prototypes has indicated the need to take into account some critical issues including a) production resources, b) hand-on experience, and c) the seductive power of virtual video prototypes.

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1. INTRODUCTION

Currently, there is an increasing interest in pervasive computing environments in which computers are everywhere, for everyone, at all times—a situation that fundamentally changes people's everyday lives. According to Thackara (2001), only a fraction of the microprocessors produced today go into desktop computers, whereas the majority become an integrated part of the physical environment. Already today, the primary mode of access to information from the Internet is shifting away from desktop computers toward mobile phones, television sets, information kiosks, and all kind of physical devices. Information and communication technology is becoming integrated into everything from cars and domestic appliances in people's homes to the buildings in which they work and live. The computer as we know it today is disappearing, and new relations between the digital and the physical are emerging. As designers of computing technology, we need to be able, in the design process, to master visualization technologies that reflect that we are designing technologies that are an integral part of our physical, 3D environment.

The virtual studio or virtual set makes it possible to use digital 3D models as sets in real time instead of scenography made from wood, steel, cardboard, or other materials (see, e.g., Lervig & Madsen, 2003; Moshkovitz, 2000). Live recordings in a blue studio with real objects and people can be mixed with computerized models. Traditionally, this technology has been used to produce television programs such as news reports and quiz shows.

Pervasive computing applications are characterized by the fact that computing power is an integrated part of the physical environment, and because the physical environment is three dimensional, the virtual studio technology, with its unique potential for visualizing digital 3D objects and environments along with physical objects, offers an obvious path to pursue in order to envision future usage scenarios in the domain of pervasive computing. We label the use of this kind of visualization *virtual video prototyping*.

Virtual video prototyping grew out of a number of information systems design techniques along with approaches to visualization in the field of architecture and set design, which we briefly review at the beginning of this article. After a basic introduction to the virtual studio technology, we present a selected set of virtual video prototyping cases, which we then use as the platform for the discussion at the end of the article. The aim of the discussion is to pinpoint advantages and disadvantages of working with virtual video prototyping as a medium for communicating design solutions in comparison with examples of other three-dimensional work methods in the field of design.

2. DESIGN AND VISUALIZATION METHODS

The virtual video prototyping approach builds on qualities from the field of user-centered design as well as from the field of architectural work methods. This section introduces some of the work methods and ways of making visual representations in the two fields of practice.

2.1. Information Systems Design

The virtual video prototyping approach combines qualities of a number of recognized design representations, including scenarios, mock-ups, prototypes, and video.

In an attempt to identify the distinguishing features of a *scenario,* Kuuti (1995) referred to the original discussion in *SIGCHI Bulletin* and pointed out that, despite the lack of a clear consensus, there seems to be general agreement that a scenario is "a description of an activity, in a narrative form" and that "when scenarios look at a system they do it from the outside, from the viewpoint of the user" (p. 20–21). A scenario usually assumes a textual form—perhaps with some accompanying illustrations. The predominant understanding of what constitutes a scenario takes the broad context of use into consideration, including the resources and goals of users. An example of this is the scenarios for an interactive art installation presented by Horn, Svendsen, and Madsen (2001). In this case the scenarios illustrate the physical surroundings ("The setting is an installation in a large room, with other activities going on"), the user ("The user is open to experiencing and experimenting with the installation"), and the activity in terms of the user's interaction with the system ("She moves about and the figure moves with her"; pp. 397–398).

Mock-ups (see, for instance, Ehn & Kyng, 1991) are low-tech design artifacts that simulate future technology and use physical materials such as cardboard, paper, wood, and slide projectors. Despite the lack of detail and functionality, mock-ups have proved to be a powerful means of providing users with "hands-on the future"—that is, it is possible for users to try out currently unavailable technology. For instance, Kyng (1988) and Ehn and Kyng (1991) reported how in the late 1980s, they and their colleagues used a slide projector to simulate a high-resolution display not available at that point in time. Regarding the quality of mock-ups, we find that they are inexpensive to make as well as easy to understand and modify. Hence, mock-ups afford the possibility to quickly and economically explore alternative solutions and even to experiment without the limitations of current technology.

According to Floyd (1984), a *prototype* is "an early practical demonstration of relevant parts of the desired software" (p. 2), which is some kind of software implementation as opposed to mock-ups made in physical materials. A horizontal prototype implements part of the interface, whereas the term *vertical prototype* refers to the kind of prototype where selected functionality is implemented. In the world of prototyping, a fundamental distinction is made between an *explorative prototype* and an *experimental prototype.* An explorative prototype plays the role of clarifying requirements and exploring the space of possibilities, whereas an experimental prototype is used for determining the adequacy of a solution. Prototypes are powerful means of involving users in the design process because they enable users to encounter a future work situation by getting a hands-on experience as opposed to only reading a description and in this way play an important role in communicating unarticulated aspects of the users' work (Bødker & Grønbæk, 1991).

Prototypes nevertheless have a strong visual appeal and are a powerful means of communicating a technological solution and thus may direct expectations in an unrealistic way or give people the impression that a technological solution already exists.

Mackay, Ratzer, and Janecek (2000) have coined the term *video prototyping* for the process of videotaping the use of physical prototyping material (paper, transparencies, Post-It notes) when acting out an interaction idea as part of a design process. In their experience, this technique produced detailed ideas

Figure 1. **Design Techniques**

	Material	Modification	Focus	Hands-on
Scenarios	Text	Easy	Context and Interaction	Detached reflection
Mock-up	Physical	Fairly easy	Physical	Hands-on
Prototypes	Digital	Fairly difficult	Interface and Functionality	High degree of hands-on
Video-prototypes	Physical	Difficult	Use	Hands-on during production
Virtual video-prototypes	Primarily digital	Difficult	Use, Context, Space	Some kind of hands-on during production

that could be directly implemented in a software prototype. Their general observation is that ideas that were videotaped were more likely to have an impact on later design activities.

Virtual video prototypes and the design techniques mentioned here contribute, each in its own way, to visualizing and communicating a design idea. First of all, they are different with respect to their materials (see Figure 1, which, in a schematic and simplified form, provides a rough comparison). The material is the fundamental quality—in itself quite uninteresting—that has implications for the other categories: which aspect of the design the technique covers, how easily the design representation may be modified, and—most important—to what extent a hands-on experience is supported.

The schema is certainly a simplification—for instance, it states the conventional wisdom that among the qualities of mock-ups is "ease of modification," whereas a virtual video prototype is considered to be heavy technology that is difficult to modify. But imagine a scenario in which developers are creating a future work environment with displays integrated in walls and furniture, in which case a virtual video prototype would be much easier to change than a mock-up.

2.2. Architectural Work Methods

Designers and architects are in general used to working with three-dimensional constructions and spatiality and have therefore developed a range of tools for communicating spatial design ideas. For example, they often use *reference images* to communicate elements of a design artifact. Reference images are typically photos illustrating features or parts of other design objects. They are often used for inspiration, communicating materiality and tangibility, or describing spatial qualities.

The most common communication tool in relation to architects' and designers' tasks is the *2D drawing*, illustrating ground plans, facades, and sections. The drawing can, for instance, be hand-drawn or based on three-dimensional CAD models. The 2D drawing has become the main communication medium between designers, engineers, and the production process, even though the design objects often is three dimensional and may be even based on complex curvature. Despite the fact that the 2D drawing becomes static by being printed on paper, its precision and simplicity still make it a powerful tool in industrial design, planning, and building processes. It is often seen that a complex 3D structure such as a building is only communicated through 2D drawings—such as ground plans, facades, and sections. One could argue that the more sections produced, the more precise the spatial description; but it still only vaguely communicates 3D qualities and relations.

To be able to communicate what 2D cannot, designers often use drawings in combination with *physical scale models*, which can vary from simple cardboard models to more detailed and elaborate models of lasting material, such as wood, metal, plastic, and so on. Scale models are often used to sketch and describe spatial relations between the context and the actual proposal, and they can reveal the inside of a building and thus allow the user to imagine himself or herself inside.

Full-scale physical models are often referred to as *mock-ups,* whose main advantage is that they illustrate real size and can therefore be used to test bodily issues, such as ergonomic and spatial configurations between the mock-up and the user. Like scale models, mock-ups can range from quickly made design artifacts—for instance, to demonstrate real-size volumes in context—to more refined representations of design, used by industrial designers to test aesthetic qualities and use. An example of a mock-up is the winning project of the competition for the extension of the Royal Theatre in Copenhagen, by the Norwegian architect Sverre Fehn, whose proposal was demonstrated and discussed as a physical mock-up.

In the last decade it has become more common to use models based on *3D modeling* and animation tools. A 3D modeling and animation tool is software that allows the users to create and manipulate digital 3D models; to work with materials, textures, and light; and, finally, to output rendered still images and animated sequences. The computer models can be used to discuss design in all scales, ranging from nanotechnologies to industrial design, building architecture and urban planning, and so on.

Another benefit of computer models is their capability of expressing design over time. Not only through predefined and animated models but also by the use of more advanced simulations of physical behavior maybe even generated in real time.

The schema in Figure 2 summarizes the qualities of the examples of architectural work methods discussed here.

3. TECHNOLOGY[1]

The virtual studio is a video technology that makes it possible to combine videos of physical objects such as people with video images generated in real time from digital 3D models (see Moshkovitz, 2000). This method results in productions that can be taped live, with only a limited amount of editing, or broadcast directly, allowing for real-time interaction between the television viewer and the studio in which the filming of the physical objects takes place. This can, for instance, be used in election broadcasts, where election results can immediately be visualized as 3D graphics, and in viewer polls, where the

1. This section is based on Lervig and Madsen (2003).

Figure 2. **Examples of Work Methods in the Field of Architecture**

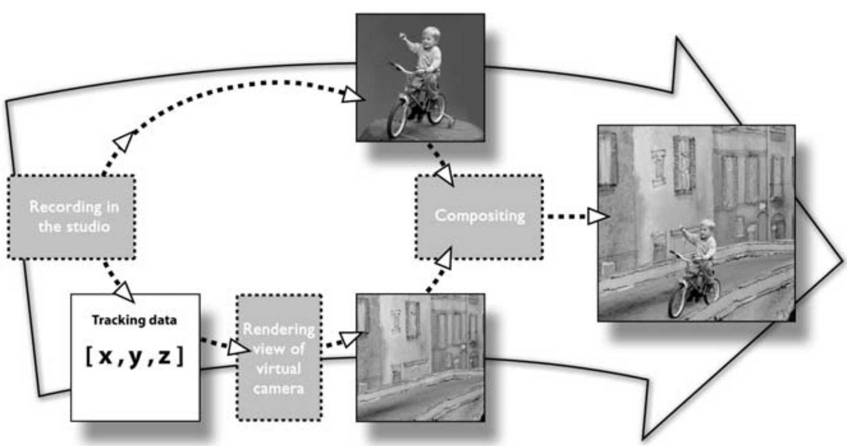
	Material	Modification	Focus	Use
Reference image	Digital and Physical	Easy	Basic idea, Principles, Atmosphere	Communicate the basic idea
2D drawing	Digital and Physical	Easy	Measurable, Perspective	Precise measurable communication
Scale model	Physical	Fairly hard	Overview, Outside, Overall structure, Landscape	Testing, experiments, sketch, meetings, presentations
Mock-up (1:1)	Physical	Fairly hard	Bodily and Contextual Relation	Testing, presentations, hands-on
3D modeling	Digital	Easy	Use, Spatiality	Perspectives, lights and surfaces, animation and dynamics
Virtual video prototyping	Primarily digital	Fairly hard	Use, Context, Spatiality	Perspectives, lights and surfaces, animation and dynamics, real time

results can generate elements that are part of the digital 3D set. In spite of the delay—40 ms to 200 ms for calculations and synchronizing—the virtual studio is said to operate in real time.

For years, television broadcasts have utilized blue screen technology. For example, in weather reports the studio host stands in front of a blue or green surface, and this monochrome field is replaced by a weather chart in the final television picture. The limitation of this classic blue screen construction is that it is impossible to zoom or move the camera. The 3D versions of a virtual studio make it possible to work with a spatial model on the virtual set, where one can put the camera on one's shoulder or on a tripod and move around in the virtual scenography.

In principle, the technology works like this: Physical objects, including people, are filmed in a monochrome, usually blue, television studio. A tracking system registers the positions of the cameras and the focus and zoom adjustments. This information is sent to the computer, which handles the virtual scenography in the shape of a 3D model so that it can (a) match the virtual camera in the virtual model to the physical camera in the monochrome studio and (b) from the position of this virtual camera render a picture whose position and focus are identical to the picture that the physical camera is taking at the same time. We now have two pictures in the system: one taken by the real camera, in the monochrome studio, and one generated by the computer, based on a camera position replicating that of the real camera. These two pictures meet in the keyer, where the background color in the picture from the monochrome television studio is removed and replaced by the computer-generated picture (see Figure 3).

Figure 3. **Schematic overview of the process.**



Advanced 3D models are made using an external 3D modeling tool such as the ones used for architectural visualization. The 3D models are then imported into the software used in the virtual studio, which is created and optimized for real-time production. Or, the 3D model is made directly in the software used in the studio, which means that the tool can be used to create geometric standard primitives and simple animations that, in general, do not require much calculation—which is necessary to meet the need for real-time rendering. At the same time, a large amount of ready-to-use material is available in the shape of functions and attributes not normally seen in a 3D program but which are practical in a situation where time is of the essence. The demand for simple calculation has been met by simplifying the models for use in the virtual studio and by limiting details so that lighting calculations are not particularly demanding.

4. THE VIRTUAL VIDEO PROTOTYPES

The virtual video prototyping approach has been applied in a variety of pervasive computing settings, ranging from hospitals to schools and museums. In this section, we present a selected set of virtual video prototypes that serve as the basis of discussion in the subsequent section.

The virtual video prototypes can be seen as Web casts (www.cavi.dk/vvpindex.php).

4.1. *The Pervasive Hospital Bed*

The virtual video prototype *The Pervasive Hospital Bed* is a future scenario from a hospital equipped with pervasive computing technologies (Bardram, 2003; Christensen & Bardram, 2002). At the start of the scene a nurse enters the ward and steps into the zone of the patient, as indicated by red circles on the floor (see Figure 4), reflecting that the nurse, the patient, the trolley, the bed, and the computer built into the table on the bed are aware of each other at the pervasive hospital. The bed has a built-in display that can be used as both a television screen and a computer display (see Figure 5).

The medicine tray has computing power and a display. Therefore, the patient's medicine tray and the patient "find each other," enabling the medicine tray for the specific patient to identify itself, as shown in Figure 6. The display is a computer graphical object layered on top of a physical medicine tray.

Three things happen when the right tray is placed on the patient's table: First, the table moves forward to the patient; a red glow appears around the tray when it is placed on the table (see Figure 7); and, finally, the patient's

Figure 4. **Entering an active zone.**

Figure 5. **The hospital bed.**

electronic health record is displayed on the screen, showing the medicine schema and highlighting the medicine on the tray. The table has to move forward in order for the patient to be able to read the screen.

When the nurse leaves the hospital bed, she automatically logs off the computer, and the computer monitor turns into the patient's television.

4.2. Handheld Display

This virtual video prototype illustrates the use of a handheld display. In an X ray–like manner, the display reveals the insides of closed objects by dis-

Figure 6. **The Pervasive Medicine Tray.**

Figure 7. **Context-aware applications.**

playing digital 3D representations of what is behind their surfaces. In this case a technician is checking a technical installation. He is examining the installation by moving the handheld display and hereby scans its inside. In this way the technician reveals information about, for instance, wiring and switches 3D positioned in relation to the physical space (see Figure 8).

This virtual video prototype demonstrates how the display can be used to access context-specific information. By means of a touch screen solution, the user is able to request detailed information about the displayed digital elements by tapping the display (see Figure 9).

Figure 8. **Using the handheld display to overview a technical installation.**

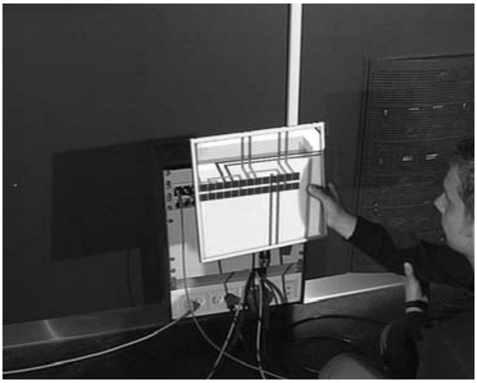


Figure 9. **Calling for context-specific information.**

The production is in this case made slightly different from the productions that directly use the virtual studio. In this case the digital model with wiring and switches is keyed into the picture using a blue plate (see Figure 10).

4.3. The Virtual Architect

The virtual video prototype is illustrating experiments with a range of spatial tools for design in a shared workspace (see Leerberg, 2002). It describes the work of two urban designers in different design situations. Without focus-

Figure 10. **Seen from the camera before keying the blue color.**

ing on specific technical solutions, the production illustrates two different scenarios:

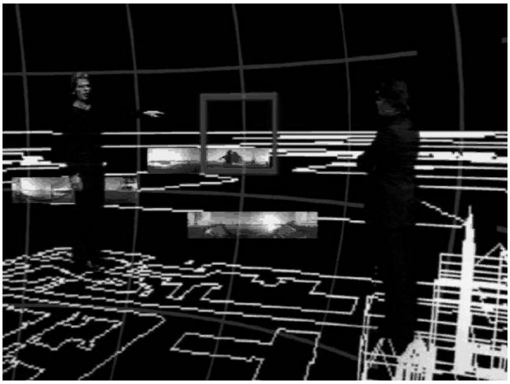
1. *Immersive—A 3D virtual workspace: a virtual representation of a design context with additional digital tools and information.*
2. *Augmented—A mixed reality workspace: a physical context with additional digital tools and information.*

Both scenarios work with digital layers of 3D-positioned information that can be manipulated. The layers can be turned on and off and by this means articulate different configurations of workspaces. The layers consist of pragmatic representations of traffic and income or more subjective layers illustrating notations of spatial qualities or relations. The urban designers can control the digital tools and layers by gestures, voice control, and so forth and thus dynamically arrange the digital spatial artifacts and their relations.

The virtual video prototype begins with the immersive scenario, where two urban designers define and construct their design space by loading different layers representing, for instance, concepts, measurements, and context. They turn on and off the layers and become immersed with information about an industrial harbor area (see Figure 11). In addition, the sequence demonstrates how the two architects can virtually travel around a large context model by turning on new context layers or by tapping marked areas that teleports them to a new position.

The next part of the virtual video prototype illustrates the augmented scenario. The two urban designers are now situated in a physical context and ex-

Figure 11. **Immersive: The urban designers are working in a purely virtual workspace discussing a design task.**



plore the surroundings, again by turning digital layers on and off. As seen in Figure 12, they are investigating the possible configurations of their design space.

One of the architects is sketching an object in 3D by having his hand tracked, which enables him to draw directly in the virtual space. The transparency of the 3D object is adjusted and different positions and angles are tested in relation to the real context. Finally, the building is examined from its inside, and its transparency allows the two urban designers to see through it and keep the orientation (see Figure 13).

Figure 12. **Augmented: The urban designers are working in the physical context superimposed with additional tools and information.**

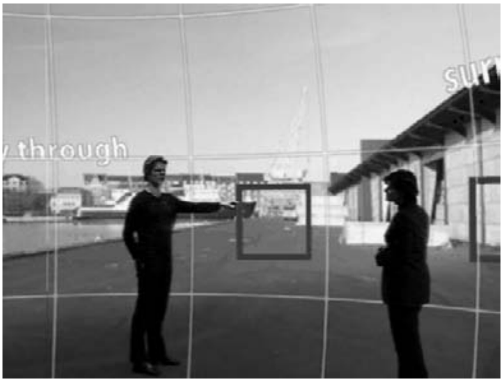


Figure 13. **Investigating a design artifact that is seen augmented onto the real context along with additional notations and information**

4.4. *Playful Interaction*

Playful Interaction is a conceptual vision of a future architectural office (see Bouvin, Christensen, Grønbæk, & Hansen, 2003; Grønbæk, Gundersen, Mogensen, & Ørbæk, 2001). The virtual video prototype illustrates ideas and concepts for playful interactions between people, materials, and appliances in a pervasive working environment (Eriksen, Krogh, & Ludvigsen 2003). The video illustrates technologies available today as well as future ones, envisioning how digital information can be sent, received, and displayed seamlessly between walls, floors, and furniture through gestures, moving physical material, and interaction devices such as a ball.

Playful Interaction follows the architect Christian during a day at work. In the first scene Christian arrives at work and enters his office, called a *niche.* He physically activates his niche and workspace by pulling down and angling his table, which is attached to the wall. He furnishes his surroundings with digital text and images by using a ball, as seen in Figure 14. By pressing the ball toward digitally displayed material, he collects it and attaches it again on any surface by tapping or throwing the ball toward it.

Christian lays a small pile of paper on his table, and additional digital information appears beside it. He arranges the digital and physical information, and later, when he collects the pile of paper, the digital information is visually sucked into the paper, illustrating that they are now linked together.

In the next scene, Christian prepares a meeting. He has brought the pile of paper, which activates the linked digital material on the table in the meeting room, called the *Cocoon*. He begins to prepare a presentation of the material by picking up single digital items with the ball and moving them to the wall by

Figure 14. **Picking up documents and furnishing the individual workspace with the ball, which extends the user's range.**

throwing the ball. By pulling, moving, and rotating the ball, Christian scales, moves, and rotates the digital material on the walls of the Cocoon and herby organizes the material for the meeting (see Figure 15).

The next scene takes place at a central place in the office building with an interactive floor containing a mixture of documents published for inspiration and for colleagues to share their knowledge. As seen in Figure 16, Christian meets a colleague, and they discuss a document on the floor; they tap documents, exchange material, and pick up digital information by using the balls that gives a physical dimension to the interaction.

Figure 15. **Christian is arranging his presentation.**

Figure 16. **Christian is discussing a document with a colleague shown on the interactive floor.**

At the end of the day Christian and his colleague Martin rearrange their adjacent niches into an informal meeting place: They furnish the walls with digital material brought from the interactive floor and discuss the material while dynamically rearranging it with balls.

4.5. The Future Interactive Classroom

This virtual video prototype takes place in the near future, where we meet a group of pupils and a teacher working in the science lab of an elementary school (see Figure 17; Bouvin, Brodersen, Hansen, Iversen, & Nørregaard,

Figure 17. **The science lab.**

2005). The speaker lets us know that they are working on a project about insects. A screen on the central table allows the pupils to video conference with another group of pupils, doing field studies at a lake.

At the lake the pupils are collecting different kinds of insects and data about the existing biotopes by examining and documenting the specific place. They use online PDAs to communicate their observations and send live audio and video as well as high-resolution images to their teammates in the science lab, as seen in Figure 18.

A question arises in the field, and the pupils in the science lab try to help by looking up the answer in books, at online libraries, and on the Internet. Hoping for an answer, the science lab contacts an expert in insects, a biology professor, working on the specific subject. The professor is invited to join the video conference and is thus easily introduced to the situation (see Figure 19).

To answer the pupils' question, the professor finds a 3D model of a dragonfly. By sharing the 3D model, the professor allows the pupils to access and see the model of the insect. The model of the insect is shown on monitors and projections on the walls of the science lab as well as through a head-mounted display made available to the pupils by the lake, as seen in Figure 20. All the material is collected in the science lab and organized for presentation. The pupils integrate the 3D model into the team's digital portfolio and link parts of the digital material to physical artifacts. For instance, they link a digital video-recording to a jar with insects.

The last scene takes place in the pupils' classroom (Figure 21). By using a big screen, they present their work to the teacher and their classmates. All the material gathered has created a dynamic collage consisting of movies, images, and text, and it is partly navigated by using the physical artifacts linked to the digital material. For instance, one of the pupils activates a movie by placing a

Figure 18. **Field studies.**

Figure 19. **Insect expert.**

Figure 20. **Superimposed 3D model of a dragonfly.**

jar near the big screen and controls *play, stop, forward,* and *rewind* by turning the jar as though it were a jug wheel.

4.6. KRAM

The opening scene is a view down a street; on the lefthand corner of the street is an organic building (see Figure 22). As one approaches the building, it becomes evident that the building has huge displays integrated into the facade, which reflect the activities both inside and outside the building. The next scene is from one of the corridors of the buildings, which reveals that the wall, the ceiling, and the floor are one huge integrated display. In a subse-

Figure 21. **The pupils present their work in the classroom.**

Figure 22. **3D model of building composited with real footage of the context.**

quent scene a person pushes the facade with his hand, and the display of the building responds with what looks like ripples in a pond.

4.7. The Museum Curator

This virtual video prototype illustrates new potentials for visually enhanced environments based on augmented reality technologies.

The Museum Curator follows a curator working at a museum, and the scenario exemplifies some of her routines during the planning of an exhibition. As seen in Figure 23, the curator is working in her office in the first scene. By using three-dimensional virtual planning software, she tests different configu-

Figure 23. **Curator preparing the exhibition.**

rations of digital representations of paintings and sculptures in a virtual model of the gallery areas.

Using a handheld device and a head-mounted display, the curator loads the finished gallery configuration. She calibrates and adjusts the virtual space in relation to the building, enabling digital representations of art pieces to be 3D positioned and superimposed onto the physical space.

The curator turns on a guidance system that shows a line of dots through the head-mounted display, starting at her actual position and ending at her destination, the gallery space, where she wants to go (see Figure 24).

Entering the gallery space, she meets a colleague who has been working on her plans for the exhibition. The colleague is also equipped with a handheld

Figure 24. **Curator led by guidance system.**

Figure 25. **Positioning virtual paintings.**

device and a head-mounted display, which is automatically updated with the curator's work.

The following scene demonstrates how the setup can be used to move and test configurations of virtual representations of paintings in the physical context. A position is found for a painting, and finally, the physical painting is hung in the same position as the virtual one, as seen in Figure 25.

The last scenes are about the planning of an interactive sculpture that is partly physical and partly virtual. The scene illustrates how the technology can be used to test positions of the sculpture, by placing virtual representations in space, and to demonstrate how the visitors are able to interact with the virtual parts of the sculpture, by moving and combing the pieces of a 3D puzzle like a piece of art.

5. THE PRODUCTION PROCESS

In general, the making of the virtual video prototypes took place as a cooperative effort between people experienced with using the virtual studio as a design technology, people from the research group working in the specific field in question, and, in some of the productions, potential users. In all cases, the initial meeting among people involved started out from the observation that the virtual studio has shown to be particularly suited for visualizing physical and spatial aspects of the integration of computing power into the environment. In addition, the production processes shared the characteristic that the teams agreed on making a sketch production rather than a high-end production, which further indicates that we are talking about a virtual video prototype regarded as a tool for testing ideas and generating new ideas. The majority of the production was made live to tape.

5.1. Live to Tape

The earlier described virtual video prototypes have showed that to determine which story to tell and how to tell it seems to be the main issue. In most of the cases, people involved from the research projects possessed detailed knowledge about the domain of application in question, providing an abundance of information for the story, including the physical setting and the dialogue. For instance, the production of the pervasive health care prototype (see Bardram et al., 2002) was based on extensive field studies and involved both nurses and doctors writing the dialog. In addition knowledge about state-of-the-art computer technology was instrumental as well. At this point in the process the different crews discussed the level of abstraction, typically without any final decision. It seemed important from the beginning of the process to choose a visual language that could communicate the ideas of the whole crew and, at this early state, have the target group of the production in mind.

The next step is a storyboard, often based on 3D models that make it possible for all of the participants to discuss the spatial and narrative components of the prototype (see Figure 26). In that sense the set design and the story are created on each other's terms; the fact that the story takes place in a specific location forces the participants to clarify unresolved matters relating to the narrative and its 3D space.

The team's work with 3D models in the process of storyboarding makes it possible for them to convert the geometry to be used in the virtual studio, where it can be further manipulated by the virtual studio software. In addition to the increased efficiency of the workflow, this direct link between models used in the storyboard process and the final set gives the team a common idea of the spatial parts of the virtual video prototype early in the process. Sharing a spatial idea in addition to sharing the traditional texts and images has demonstrated to be a dynamic and expeditious way of working—even though it is

Figure 26. **Element of storyboard from** ***The Pervasive Hospital Bed.***

not all the team members in a production that master working with 3D models.

An issue that the participants often address at this point in the process is which part of the scenography should be physical and which part should be virtual. The basic principle is that only objects that do not physically exist or have not yet been designed are virtually created. In productions using the virtual studio, it is well known that a combination of both virtual and physical objects in the scene blurs the boundary between the two. People in a predominantly virtual environment often do not seem to merge well into the set, whereas a high degree of mixing of physical and virtual realities tends to create a more credible totality. Of course, this issue has to be seen in the perspective of the specific production and the visual language agreed on by the team members. If a schematic or abstract set is selected, then physical objects will probably not help making people merge well into the set, and it might be a better choice to use few simple and designed objects with a visual appearance not loaded by too much meaning and conflicting styles.

In the productions the teams tested numerous computer models in the studio, clarifying tactile and physical design parameters such as materials, textures, light settings, and ergonomic issues. The computer models were tested in relation to the physical objects on the set; virtual objects had to match physical objects; and their movements were designed to avoid interpenetration as seen from any perspective.

The final step in the process is the production in the studio. Working on the set with real-time computer models makes it possible to discuss the output on the fly. The directors and people on the set can easily comment on and change both the story and the set design—especially the virtual set.

During the production process, the 3D facilities of the studio contributes to an ongoing evaluation of lights, angles, and composition. The composite meeting of physical objects, talents, and the virtual set, examined through the perspective of the physical camera, is live displayed on several monitors and a projection on a wall. This makes it easy for the crew to share a common idea of the production and discuss last-minute changes to the virtual video prototype and hereby have the freedom to easily go back and forth in the process and redesign and compose the set and a possible narrative.

Dealing with a production containing physical and virtual objects in motion requires some rehearsal to avoid collision between people and the virtual set. Because of such possible problems, the teams have to invent technical solutions, such as allowing people to place physical props onto the virtual set while acting. Different sizes of chroma key blue boxes are placed strategically onto the set so that they match up with virtual objects that become their invisible materialized surface.

5.2. Postproduction

In addition to work methods based on storyboarding and live to tape, described in an earlier section, all of the virtual video prototypes detailed here have undergone some amount of postproduction. In general it has been a matter of editing, producing speech, creating titles, and making minor color corrections—all adjustments and techniques that influence the aesthetics and finish of the virtual video prototype but not the spatial construction and content of the virtual video prototype.

An exception to this is the production entitled *KRAM,* which was produced on the basis of postproduction methods only. The aim of the video is to give a clear impression of a future building on a specific site and furthermore to describe the interaction between the building and its surroundings. Considering that the site was not fictive but already there, ready to be used and built on, the production team wanted to use real footage and therefore had to introduce postproduction software that could combine the virtual model of the building and the physical site.

In addition to the outdoor takes, parts of the virtual video prototype are sequences illustrating the inside of the building. To be able to control more advanced mapping techniques, light settings, and shadows what than the virtual studio allows, postproduction was chosen in the indoor sequences. By using a 3D modeler, sequences of virtual set and video feeds recorded on the real site were composited. In addition there was a desire to introduce people in the video, not only as life-giving elements, but also as part of the narrative and the interaction with the building. This was achieved by recording actors in the virtual studio on a blue background, creating matte signals based on the blue color, and, finally, using the matte signals to mask the recorded actors now 3D positioned on planes in the set of the 3D modeler.

In general terms, the postproduction turned out to be a slow and less dynamic production method than the one possible in the virtual studio. In terms of workflow and the possibilities of making fast changes in the production process, it demonstrated that the virtual studio has several advantages. The real-time output gave all the crew members, designers, technicians, and actors the possibility of commenting on the final outcome on the fly. In contrast, most of the composite processes turned out to render quite slowly, sometimes one frame per minute, which did not improve the situation in terms of the time lag.

On the other hand, the postproduction methods do have other advantages. If it can be accepted that a production is time-consuming, graphics quality is limited only by the software and the skills of the operator.

6. DISCUSSION

The use of the virtual video prototypes has proved that they are not only a powerful means of communication but can also play a productive role in testing and generating design ideas. In both types of cases, a virtual video prototype in particular supports paying attention to physical aspects and interaction issues.

6.1. Communication

Virtual video prototypes are characterized by the ability to communicate pervasive computing design ideas such as the use of RF-ID tags and new kinds of integrated displays in the physical environment. Pervasive computing is just coming into existence, and the virtual video prototypes have contributed in a very compelling way to communicating which kinds of computer application will make up the next wave of IT. In the case of the pervasive health care project Bardram (2003) stated:

> The two virtual video prototypes have been a very powerful means of communicating the concepts of *application roaming* and *activity based computing* to nurses and doctors joining the project at different stages of a research and development project. (Interview with Jakob Bardram, 2005)

On the other hand presenting sophisticated design concepts in such a concrete way involves the risk that things appear to be more simple than they are, as seen from a technical perspective.

Herman Bailey, the independent consultant who has developed the design concept presented in the Museum Curator and has primarily been using it as a presentation tool for people who are potential business partners, offers the following assessment:

> The strongest argument for using this medium has been that it has been able to create an illusion of an idea without having to go into technical detail. This has two advantages; one is able to get feedback from individuals who may have expertise in other field that are relevant to the successful commercial development of the ideas, investment in technical development can be deferred until a later stage in the process. … Being able to present ideas in an easily understandable format is essential for generating enthusiasm to start up a development project. (personal communication with Herman Bailey, 2005).

The virtual video prototypes presented in the first part of this article have been used not only to communicate design ideas among research and development team members but also to bring local and national politicians, visitors from industry, and so on, up to date about state-of-the-art IT research. Ole Lehrmann, who is the executive director for the Alexandra Institute (a research-based limited company, see www.Alexandra.dk), reported,

> Virtual video prototypes is an excellent way of communicating that the IT-City Katrinebjerg is a dynamic and visionary research environment. (personal conversation with Ole Lehrmann, 2004)

Excerpts from the virtual video prototypes have also in a number of cases been shown on national and local television as part of the communication to the general public. For this purpose the virtual video prototypes such as *The Pervasive Hospital Bed* and *The Future Interactive Classroom* have proven to be particularly valuable, most likely because they tell about specific situations and places that are familiar and of interest to most people—the school and the hospital.

The communicative power stems from the high degree of realistic presentation of concrete situations in a story-driven rather than a technology-driven way. Video artifacts, as suggested by Mackay and colleagues (2000), are in a similar way story driven, but because they are made from physical materials, they require the viewer of the video to fill in some gaps. Video artifacts are often low quality due to use of handheld cameras, and only little attention is paid to light condition. On the positive side, the cost of making video artifacts is significant lower than the cost of making virtual video prototypes. Moreover, video artifacts do not, for good and for bad, have the seductive power of virtual video prototypes. Both kinds of video seem to require to be presented within the right verbal context in order to explain that the video does not show the final design.

6.2. Testing and Generating Design Ideas

Some of the virtual video prototypes, such as *Playful Interaction* and *KRAM,* are more open-ended than others, such as *The Pervasive Hospital Bed* and *The Future Interactive Classroom*. The making of the video *Pervasive Healthcare* had the specific purpose of suggesting a way of solving some previously identified issues and problems at a hospital (see Bardram et al., 2002). In this respect *The Pervasive Hospital Bed* resembles what is called an experimental prototype in conventional prototyping terminology (see Floyd, 1984). The video is a concrete story about what happens at a hospital on a specific day. *The Museum Curator* is also a concrete visualization suggesting a specific solution to be used at a museum, including specific design ideas being tested—for instance, the idea of a guidance system that shows a line of dots through the head-mounted display.

Playful Interaction is different; though it is clear that the scenes of the video prototype are from an architectural firm, it is more abstract. *Playful Interaction* offers suggestions about how to organize the spatial configuration without the intent of proposing a specific solution; on the contrary, it raises for discussion the question of how to integrate computing power and physical space. In conventional prototyping terminology, this refers to an explorative prototype (see Floyd, 1984).

The Virtual Architect is also quite abstract and stimulates thoughts about new ways of visualizing architectural proposals in the context of the future construction site. Thomas Leerberg and Tina-Henriette Christiansen, the architects behind the production *The Virtual Architect,* stated:

> The Virtual Architect is not only a visualization of an idea, but an active discussion and use of the Virtual Set. We wanted to challenge the technology as a tool and as a deliberate strategy we have tried to push the use to create new ideas. (Interview with Thomas Leerberg and Tina-Henriette Christiansen, 2004)

The Virtual Architect is an explorative and intuitive use of the virtual studio, the single shots being less planned than during the other productions. Basically, a tape ran constantly during discussions of the set and the project, recording hours of material that were later edited into a production that constructed a narrative chronology.

KRAM was made for the purpose of raising for discussion the visual quality of the buildings in a particular area. A building with such an organic form and with integrated displays in a radical way is unlikely to be built at the specific site.

Though *Handheld Display* is about a specific work situation, it has proven to be quite stimulating, generating new ideas for the use of such a handheld display—for instance, when shown to museum people, it triggered the idea of making signs superfluous, replacing them with digital overlays on top exhibits. Such virtual video prototypes are like *generative metaphors,* as discussed by Schön (1979), who has coined the term to express the kind of metaphors that, rather than communicate a specific solution, stimulate the generation of new ideas. It seems that brief situations have more generative power than closed narratives.

6.3. Physical Aspects

The production of the virtual video prototypes created awareness of physical aspects that may otherwise go unnoticed. For instance, the design of the table in the *The Pervasive Hospital Bed* virtual video prototype raised issues such as cleaning, hygiene, materials, and access from the end of the bed, which actually created the specific design solution appearing in the video. In that respect the virtual video prototypes are parallel to the aforementioned mock-up techniques. The composite signal that blends the physical set parts and actors with virtual scenography construct (in a representative way) a bodily relation between the set and the actors. The use of monitors and projections on the wall inside the blue studio during the takes supports the relations between the physical and the virtual parts of the production, and interviews with the actors that have taken part in virtual video prototypes show that they remember themselves on the virtual set—not in a blue room (see Figure 27).

In some cases the physical and spatial aspect is addressed by making almost everything digital, as in *Playful Interaction,* in which the office building and the majority of the furniture are created digitally. In this case we are talking about fairly large objects, like furniture that is not available today, which is much faster to create digitally than to build or mock up in physical materials. In this way it was possible to explore and experiment with the spatial aspect of integrating displays in the furniture, the wall, and so forth in various ways without being restricted by economic factors, building materials, or physical limitations in general.

But in other cases new digital elements are built onto existing physical objects, first of all because there is no reason to create digitally what already exists and is easy accessed, such as in *The Pervasive Hospital Bed,* where an ordinary hospital bed is augmented by a small table with a monitor, which is one of the subjects of investigation. An extreme case in this respect is *KRAM,* where an interactive building is placed on an exiting site taking advantage in the production of the present trees and city environment. One might expect that bringing together digital and physical elements would make the digital element appear more artificial; however, the combination contributes to a greater acceptance of the realism of the digital elements. This is, of course, a rather general conclusion that can easily be complicated by considering the

***Figure 27.* The pupils of *The Future Interactive Classroom* looking at a monitor and a projection on the wall of the composite signal.**

aesthetic and style of the virtual set design in relation to the physical components. In the case of the virtual video prototypes mentioned earlier, it has been aimed at achieving a fairly realistic visual expression by applying natural textures and lighting.

6.4. Interaction

One of the recurrent challenges raised during the production processes concerns the fact that actions have to be explicit, which demands specific solutions in such areas as interaction. Virtual video prototyping actually makes it possible to visualize currently unavailable innovative interaction styles; for instance, the tennis ball in *Playful Interaction* makes it possible to move a document from one place to another by simply using the ball to absorb digital material from one display and by throwing the ball in order to direct the digital material to another display. Virtual video prototypes as opposed to scenarios (Kuutti, 1995) force the designer to make explicit more details.

Related cases are *KRAM,* which illustrates the radical idea of using walls, the floor, and the facade as one huge display, and *The Museum Curator,* which envisions new ways of tracking and interacting with representations of paintings in an exhibition space. *KRAM* is, as mentioned, postproduced, and the studio was used only to record the actors; but one of the goals of *The Museum Curator* was to examine the interaction during the production. In this case the virtual studio was used in an unconventional way, in the sense that the tracking system—normally used for tracking the position of the cameras—was used to track the handheld device used in the scenes for positioning virtual art pieces. By letting a digital object be controlled by tracking data, it was possi-

***Figure 28.* Tracking a virtual representation of a painting positioned on top of the physical painting.**

ble to move 3D objects on the set in real time, demonstrating the possibilities of controlling digital objects in space (Figure 28). A lot of studies and examinations were made of the behavior and possibilities of the setup. Among other things, the experiments revealed that the actor had to practice to gain control of the virtual object, which—one might expect—would also be true for the curator of the future working with such a new device.

6.5. Critical Issues

From making and using the virtual video prototypes, our general experience has been that they constitute a productive supplement to the designer's toolbox, but we have also observed some critical issues.

Production time is certainly a recurrent issue that has been up for discussion when the design teams we have been working with initially considered making a virtual video prototype. The resources put into the productions presented in this article varies significantly. *Handheld Display* was made by two people working part-time on the production during a 2-day period, whereas *The Future Interactive Classroom* was made over a period of about 3 weeks, involving designers and the production crew. A general estimate of the resources put into the various productions is as follows: first, creation of the story line and the 3D models, 10 days; second, production in studio and on location, 8 days; last, post-production including voice over: 2 days. Compared to making scenarios or working with mock-ups, the resources required are significantly larger in the case of working with virtual video prototypes. But as pointed out earlier, making and modifying a virtual video prototype may be faster than using mock-ups when it comes to large physical elements of the design.

Virtual video prototyping has been challenged on the issue of hands-on experience, since "it is only a video" and "when you work in the blue studio, you only see a blue environment." But using the monitor with the composite signal during the production of the virtual video prototypes actually did give the participants a sense of a future work environment and the actors actually remembered themselves in the set—not in the studio. Also, when users are viewing a virtual video prototype, they are able to identify themselves as being part of the video, quite similar to people watching a movie identifying themselves with the one of the characters a movie (see Grodal, 1994; Smith, 1995).

A third critical issue concerns the seductive power of virtual video prototypes, as touched on in some of the previous discussions. A virtual video prototype may provide the impression that technology and software solutions appearing and being used already have been implemented—a problem that actually may be encountered in the case of conventional prototyping. As pointed out by executive director Ole Lehrmann from the Alexandra Institute

> In some situations where we have used the virtual video prototypes it has been difficult for people to distinguish between what is possible to implement today and what might be possible in the future. (personal communication with Ole Lehrmann, 2004)

As mentioned earlier, the communicative power stemming from the high degree of realistic presentation of concrete situation in a story-driven rather than a technology-driven way may obscure complex aspects as seen from a technological perspective. Several people using the virtual video prototypes have pointed out that in some situations (e.g., *The Pervasive Hospital*) it is not obvious what happens, and it seems clear that it is an advantage to accompany the presentation of the video with an oral explanation. An alternative approach that we are considering is making short television-spot like virtual video prototypes communicating only a single design idea.

NOTES

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