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# Toward the Digital Design Studio: Large Display Explorations

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## ABSTRACT

Inspired by our automotive and product design customers using large displays in design centers, visualization studios, and meeting rooms around the world, we have been exploring the use and potential of large display installations for almost a decade. Our research has touched on many aspects of this rich design space, from individual tools to complete systems, and has generally moved through the

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life cycle of a design artifact: from the creation phase, through communication and collaboration, to presentation and dissemination. As we attempt to preserve creative flow through the phases, we introduce social structures and constraints that drive the design of possible point solutions in the larger context of a digital design studio trail environment built in the lab. Although many of the interactions presented are viable across several design phases, this article focuses primarily on facilitating collaboration. We conclude with critical lessons learned of both what avenues have been fruitful and which roads to avoid. This article lightly covers the whole design process and attempts to inform readers of key factors to consider when designing for designers.

## 1. INTRODUCTION

For almost a decade, our lab has been exploring and investigating large displays in the context of the design process. The design process that we examine is common to several varieties of design: product design, automotive design, architectural and interior design, even graphic design to some extent. The stages and organization of these design practices may be seen to be identical to those of typical office work—from creation to presentation. However, the visual nature of the artifacts involved in design work call for unique interactions and many of the affordances provided by large displays.

We begin by introducing the design roles and activities followed by the presentation of a number of systems and designs created to address issues or to help understand the challenges and benefits of large digital displays in the studio. Physical large displays have always been used in the design process and, as we step through the activities involved in the design process, we show how digital versions of these displays could one day be used. Some of the projects shown here have been productized and have shipped to dozens of design studios around the world, whereas others remain as research prototypes.

Our research has touched on many aspects of this rich design space, from individual tools to complete systems, and has generally moved through the life cycle of designing a work artifact: from creation, through collaboration, to presentation. Not surprisingly, display size closely follows the physical needs of the activity. For example, sketching is most effective at the scale of a sketch pad, whereas a design review with a colleague is comfortably done in front of a four-foot screen. Larger collaboration sessions with a dozen people or more require a dedicated room. We find that most design activities can be properly accommodated at three display sizes: large monitors, wall-sized displays, and room-sized displays. Large monitors can be in the range of 20 to 60 in. diagonally, whereas wall-sized displays would normally be about 8 feet by 6 feet. We dub a system to be a room-sized display when multiple wall-sized displays are simultaneously used in a room to facilitate the needs of multiple users. Of course, displays exist between these sizes and may suit a number of activities more or less comfortably.

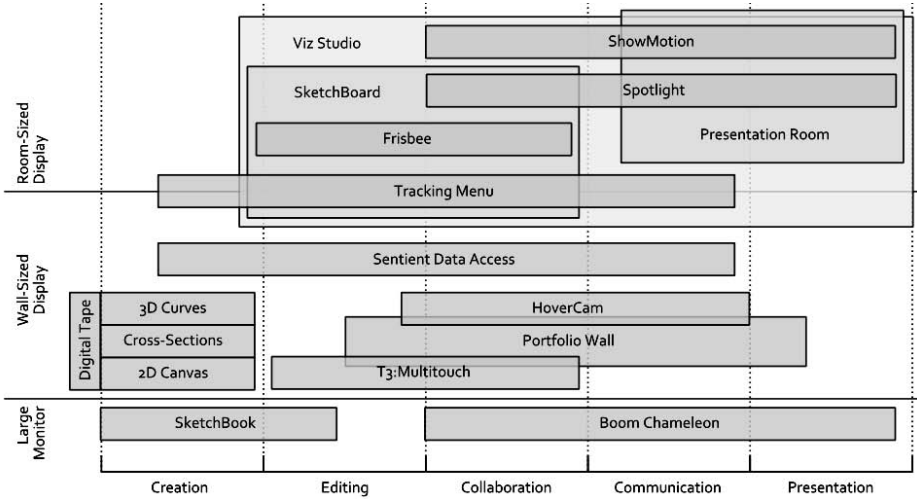
In this article we present a number of systems that can be organized across a number of display sizes and design stages. In Figure 1, we attempt to map out these systems, although in some cases two dimensions of categorization do not fully capture the intent of the system. In any case, we use this map as a guide through the detailed discussion.

In Figure 1, we see the three display-size ranges graphed against five design stages: creation, editing, collaboration, communication, and presentation. For creation, we discuss the Sketchbook project and the Digital Tape systems. Editing involves Sentient Data Access across the studio feeding terminals like the Boom Chameleon, Vision Dome, and Portfolio Wall. A number of interaction systems support content navigation during the collaboration stage such as the T3 multitouch system, Tracking Menus, HoverCam, ShowMotion, and ViewCube. The Sketchboard prototype in the context of the Viz Studio calls for tools like the Frisbee and Spotlight. Finally, the Presentation Room begins to explore final project presentations.

## 2. THE DESIGN STUDIO

Like any workplace, the *design studio* reflects the activities that go on there. Whether the studio is concerned with industrial design, architecture, graphic

Figure 1. A mapping of systems grouped by display-size (vertical) versus design stage (horizontal).



design, film design, or automotive design, we find common formal and informal spaces and objects. We find meeting rooms, casual spaces, workshops, offices, and cubicles. There are large wall-sized art boards with inspirational material or design ideas and variations (see Figure 2), physical artifacts such as prototypes, material samples, sculptures and artwork, and decorated personal spaces with tools, toys, and tape.

Despite the significant technology changes that have transpired over the last half century, the creative people working in these spaces, and the *roles* they play, have kept their places. On the management side, there are still De-

Figure 2. A design studio workshop (left) and meeting room (right) (photography by Ilene Solomon, courtesy Bruce Mau Design).



sign Managers and Creative Directors reporting to the Head of Design. Larger studios may also have Project Managers and Studio Managers. Implementing the design goals and vision are the Design Director and the Designers. Of course, people working in smaller studios may wear many of these hats at the same time.

## 2.1. Design Roles

The Head of Design is the management head and will typically set the vision and direction of the studio. This is also the person who would interact with the Client and present the final design. The Creative Director is concerned with the marketing and branding aspects of work being done in the studio and will advise on all the projects underway. The Studio Manager will ensure the smooth running of the studio and support the infrastructure. On each project, depending on the size of the project, a Design Manager (or Design Director/Art Director) and a Project Manager will oversee all aspects of the job. Finally, a number of Designers will report to the Design Manager.

The studio and the client work together to solve the proposed problem, and we call this problem-solving strategy the *design process*. Designers must adapt and develop the process to meet the constraints and parameters for each job. In some cases, the client is an individual with a specific need and direct interaction with the studio is possible. However, when the client is abstracted to mean some portion of the populace, the client is referred to generically as a *market*. In this case, the role of the Creative Director is greatly heightened as a representative of the market and as an interpreter of the guiding design qualities and goals for the project, that could be called the *brand*. Conceptually, at the highest level, the Head of Design gathers the client needs, works with the studio and the client, and presents the results back to the client. The designers collect related works and inspirational materials, and create sketches, layouts, variations, prototypes, and plans.

## 2.2. Design Activities

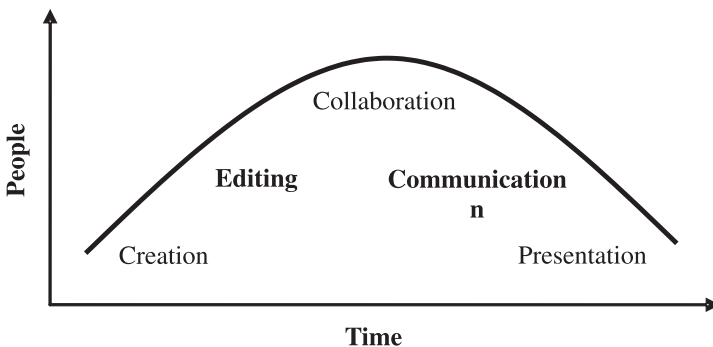
The roles and activities surrounding the design studio have been the focus of our research for almost a decade. We have visited and worked with automotive studios, industrial design firms, and animation studios around the globe. In the last few years we have also developed relationships with architects and spent time in their studios. This diversity has shown us many commonalities and some idiosyncratic activities too. The human-computer interaction community has also moved toward examining roles and activities, though more focused on the “knowledge worker” domain. The field has generally gone from user interface evaluation to user-centered design to context

and activity-based design (Kaptelinin & Czerwinski, 2007). For our purposes, we group design activities into stages related to the *design artifact*, or the outcome of the design process (see Figure 3). We arrange these activities over time to reflect the general life cycle of the design artifact. Although people of various roles may come into or leave the overall design process, or roles may change during the lifetime of a design, we have found that the number of people involved is an implicit and important part of the context of an activity. We group the major design activities into creation, editing, collaboration, communication, and presentation. Often these stages are not explicit and blend into each other as design tends to be highly iterative in nature. Next we examine the three extremes of creation, collaboration, and presentation in more detail. In Figure 3, we see that during creation, very few people are working on the project and finally, during presentation, the head of design or key designer will present the work to the client.

In looking at the graph in Figure 3, we can see that commercial computer applications have generally provided stronger solutions when smaller numbers of people are involved in the activities. Also, solutions have been weaker toward the end of the life cycle. That is, computer applications have generally focused on the creation and editing activities. For example, with the advent of desktop computers, laser printers, and illustration and drafting software, the old art table and drafting table have been replaced by machines.

However, the task of these workplaces has not changed, nor has the ambience. Figure 4 shows a typical office cubicle of a graphic designer. The computer screen is now the central object of focus; however, all of the typical design paraphernalia is still there surrounding the new virtual art table. One could argue that it is no longer possible to run a traditional noncomputerized design studio except perhaps in noncommercial settings where designers are simply creating objects for their own use, as occurs in education and craft-

Figure 3. Design artifact life cycle.



*Figure 4.* The workspace of a graphic designer.



based workshops. On the other hand, we are far from seeing a fully digital design studio. Unfortunately, the modern hybrid studio—straddling both digital and traditional methods—can experience new challenges along with the new tools.

The virtualization of design tools and processes can provide many benefits, such as support for the creation of flexible parametric geometric data, quick and easy content editing for faster design iteration, and ready participation in modern electronic communications. These benefits have also led to the globalization of design, and it is now quite common to see highly collaborative design efforts distributed across many time zones. However, along with these benefits are significant costs. Among other things, costs include the virtualization of access to data, finding the data desired, visualization of the content, and operation of the visualization tool. Of course, these costs are more acute for casual users of the system and/or remote users.

### **3. DESIGN ARTIFACT LIFE CYCLE: CREATION**

As mentioned previously, the creation activity has been well supported by computerization in the design studio. In 1982, AutoCAD was commercially available as a digital drafting tool. In 1987, Adobe released Illustrator for vector drawing. Alias released StudioPaint in 1994 with high-quality pen-based sketching tools for automotive design. In 2002, our research group helped develop a new pen-based interface for Alias Sketchbook Pro, driven by the StudioPaint engine, specifically designed for use on the Microsoft Tablet PC. These products were all intended as part of the creation activity in the design

studio for sketching, illustration, and drafting. These products had another thing in common besides a content creation purpose; they all supported activities at the approximate scale of the physical desktop.

In this critical first phase of design, it is worth considering two methods of creation: *sketching* and *drawing*. Sketching is the archetypal design activity and can be characterized as being quick, disposable, plentiful, and vague, and it is meant to suggest and explore rather than confirm (Buxton, 2007; see Figure 5). Typically, one sketch is chosen from five or six designs and is the starting point for the next iteration of five or six sketches. Once sketches have been selected and refined, designers may start making drawings. Drawing is a slower more controlled activity than sketching and conveys a greater sense of certainty and planning.

### 3.1. Sketching

As seen in Figure 1, Sketchbook is applicable in the context of creation on computer monitors and some large monitors, suiting the range of the designer's hand motion. Two key insights were made when designing the interface (as shown in Figure 6) for the Tablet PC: (a) Primary hand motion follows an arc due to the lower arm pivoting at the elbow, so place the primary UI in the lower corner opposite to the dominant-hand side, and (b) even motion along the primary arc is effortful so use in-place tool selection when possible.

The lessons learned were embodied by the design of the "lagoon" of commands placed in the lower corner of the display, and the development of Tracking Menus (Fitzmaurice, Khan, Pieké, et al., 2003) supporting rapid in-place tool selection. We discuss the benefits of Tracking Menus in a later section.

These lessons extend to larger display sizes. Human biomechanical constraints come into play when designing scalable interactions for which the

*Figure 5. Sketches from (left) automotive design and (right) fashion design.*

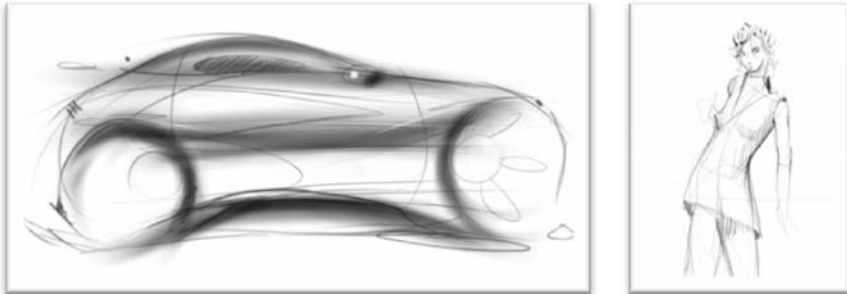
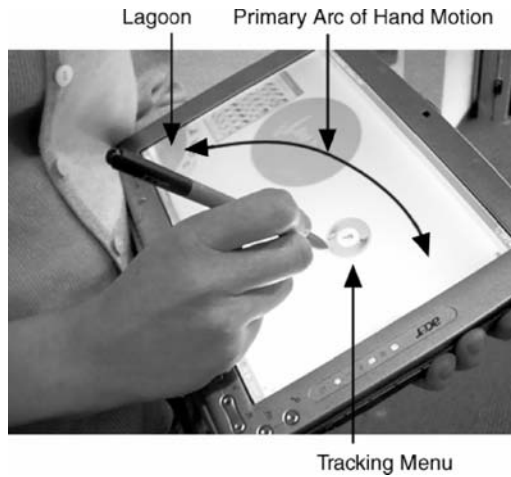




Figure 6. Sketchbook on a Table PC.



shoulder, elbow, and wrist determine comfortably accessible areas of a display. As the size of a display becomes larger, the higher up the kinematic chain of the arm that the primary arc is determined. Of course, moving up the chain also lowers motor control precision. As such, sketching becomes more difficult at larger scales and so, drawing becomes the preferred means of creation.

### 3.2. Drawing

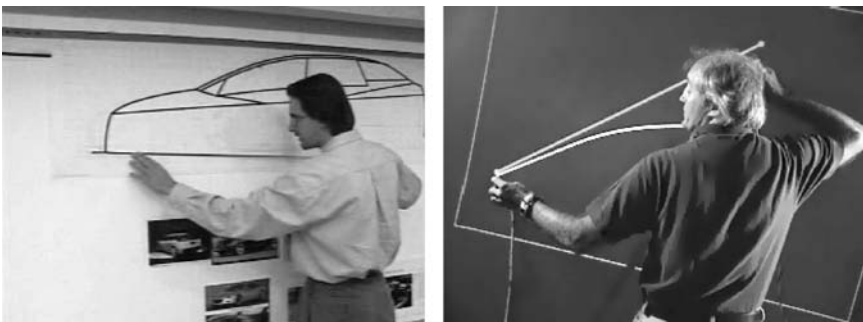
Although designers' physical skills generally exist at the desktop scale, in our experience with design studios, we found that a number of interactions throughout the design process exist at larger scales (Buxton, Fitzmaurice, Balakrishnan, & Kurtenbach, 2000). *Tape drawing* is a bimanual large scale drawing technique developed by automotive designers. This technique was developed by designers to solve the problem of creating the principle curves of a car. Although it may seem that the principle curves could be drawn at smaller more comfortable scales using ordinary pencils and paper (the same tools they use for sketching), the designers found that it was difficult to properly evaluate the curves drawn until they were enlarged to full scale. Once enlarged, unpleasant surprises would often be found. Because of the large investment needed to develop a new car, and the importance of the principal curves to the overall design, drawing these curves at full scale was the only practical solution. However, as previously discussed, freehand drawing skills do not scale well. As it happened, designers found that "drawing" with black

photographic tape met their needs. Drawing very large straight lines and smooth curves with pens and pencils is difficult, but drawing with tape “easily facilitates the generation of perfectly straight lines, and, due to the slight elasticity of the tape which allows it to be deformed, smooth continuous curves as well” (Balakrishnan, Fitzmaurice, Kurtenbach, & Buxton, 1999, p. 161).

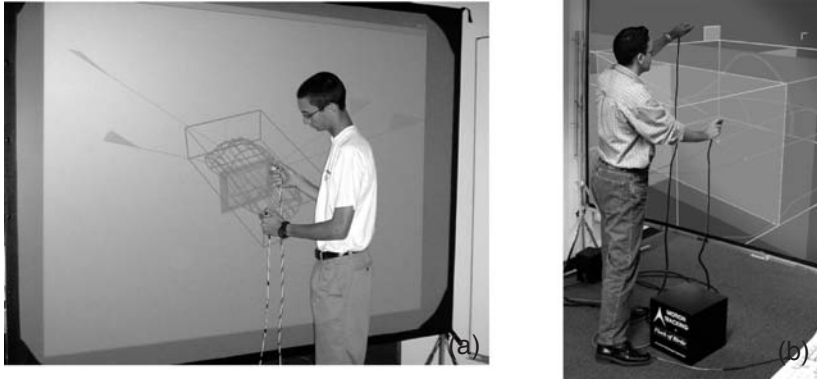
We developed a digital tape drawing tool (see Figure 7, right) which was able to capture all of the benefits of physical tape drawing with additional functionality only possible in a virtual system. Furthermore, the final stage of somehow digitizing a physical tape drawing piece, to import the data into a CAD software package for surfacing, was no longer needed. This project generated some excitement at the studios where it was shown. However, it seemed to generate more questions than answers (Balakrishnan et al., 1999) and so, we built on our initial two dimensional (2D) prototype to explore three dimensional (3D) modeling on large displays. “The very designers who rejected the use of conventional software in favor of drawing with physical tape, when given an electronic analogue of tape drawing, were asking for capabilities that the original physical technique could not provide” (Grossman, Balakrishnan, Kurtenbach, Fitzmaurice, Kahn, & Buxton, 2001).

Our improved system (Figure 8a) used tape drawing as the primary curve and line creation technique, on axis-aligned 2D construction planes spatially integrated in a 3D volume. As several traditional graphical user interface widgets would not work on the large display, we added *marking menus* (Kurtenbach & Buxton, 1993) for issuing commands in-place and switching modes. For navigation, we provided zooming and panning based on the “rubber sheet” bimanual interaction techniques designed for the T3 system (Kurtenbach, Fitzmaurice, Baudel, & Buxton, 1997). For orientation, we had an orbit tool in the nondominant hand. We also began to use “proximity to the display” as a controlling parameter. Finally, we supported *flags* as 3D handles to saved views.

**Figure 7.** An automotive designer using the tape drawing technique, and our digital version (from Balakrishnan et al., 1999).



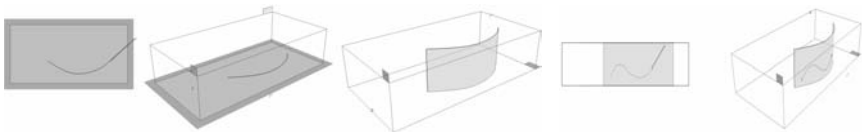
*Figure 8. (a) Cross-section modeling on large displays (from Grossman et al., 2001); (b) creating principle 3D curves on large displays (from Grossman et al., 2002).*



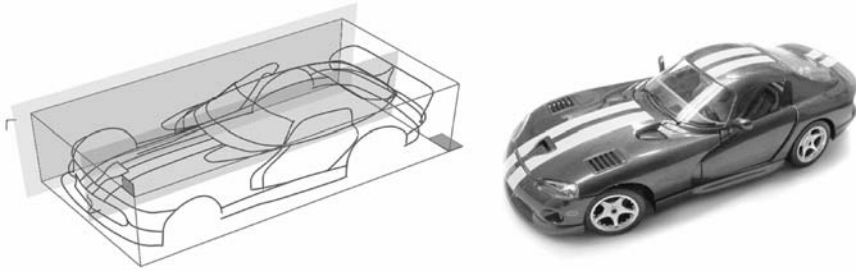
To better capture the principle curves of modern automobiles, we extended our system to support 2D tape drawing on a 3D curved plane based on a previous curve (see Figure 9). The user would first select the working plane and draw a curve, which could be extruded as a 3D curved surface. They would then move to an orthographic view of that surface and draw a second curve. In this way, a 3D curve could be drawn in a controlled yet flexible way (see Figure 8b). A critical aspect of this design was a seamless way to switch from a perspective view (for depth cues) to an orthographic view (for precise drawing). Working at arm's length from the display, users found the perspective/ortho switch to be quite jarring. We added smooth transitions between the 2D and 3D views with a novel interpolated projection method (smoothly going between orthographic and perspective projections) to address this problem (Grossman, Balakrishnan, Kurtenbach, Fitzmaurice, Kahn, & Buxton, 2002).

These techniques taken together proved to be effective in allowing the user to express complex 3D curves of the form needed to draw the principle 3D curves typical for automotive design. In Figure 10, a 3D curve network can be seen of the Dodge Viper. Note that no planar curves are used at all.

*Figure 9. Left to right: Drawing a curve and extruding it to be a 3D curved surface. Drawing a curve on an orthographic view of the curved surface (from Grossman et al., 2002).*



**Figure 10.** Principle 3D curves for the Dodge Viper together with a photograph of a scale model of the car (from Grossman et al., 2002).



This system implemented interactions supporting the physical scale needed to express automotive designs. Perhaps when multi-input technologies for large displays become viable commercial products, these prototypes may be revisited.

To summarize, the creation stage of the design artifact life cycle includes activities such as sketching and drawing. Both have been supported by digital technologies, 2D drawing more so than sketching in desktop commercial packages, though only for the small screen. The benefits of the digital versions include the expected benefits of editing and nondestructive operations, as well as unexpected capabilities such as the creation of 3D curves using the existing skills of the traditional tape artist. Of course, digital tools can directly integrate with the digital pipeline of the studio and this saves the time-consuming and error-prone digitization of the artifacts. Also, digital artifacts can easily be communicated via intranet, e-mail, and so on. Finally, drawing for large displays has some unique needs and affordances such as the use of in-place tools, bimanual input, smooth animated transitions, and careful consideration of the biomechanical constraints at play. These factors all contribute to the design of comfortable interactions at various display sizes for sketching and drawing.

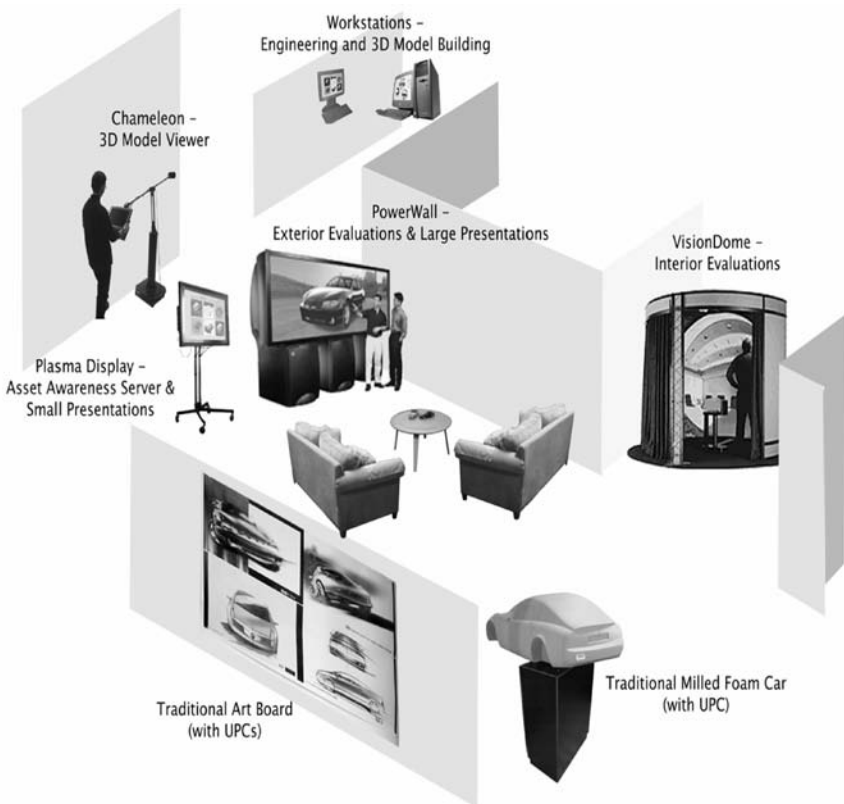
#### 4. DESIGN ARTIFACT LIFE CYCLE: COLLABORATION

As the *creation* phase of the design process moves forward toward *editing*, more people become involved. Management begins to give feedback and guidance and, at some point, major design changes are less frequent and much evaluation and discussion occurs. We call this the *collaboration* phase, the activities of which take place more in meeting rooms and at evaluation stations. In Figure 3, we see *collaboration* as the phase in the design artifact life cycle that involves the largest number of people during the overall design pro-

cess. In moving toward a vision of a digital design studio, this phase may also include the largest number of devices. Essentially, compared with the creation phase, collaboration can be characterized as *more people, more devices, and more communication*.

Our vision of the digital design studio is a fairly rich environment of activities, specialized terminals, and dedicated spaces (see Figure 11). Terminals could include typical computer workstations but could also be large displays, or exocentric and egocentric displays. To follow the movement and transition of content among and within the physical and digital realms, a tagging system was proposed (Fitzmaurice, Khan, Buxton, & Kurtenbach, 2003). In this section, we briefly present the terminal types followed by greater detail about the Portfolio Wall design as a common interface to a variety of terminals as well as

*Figure 11. Trial environment for our digital design studio prototype (from Fitzmaurice et al., 2003).*



serving as the content repository. We then show a number of interface techniques to facilitate 2D and 3D content navigation on terminals.

#### 4.1. Display Types

For many classes of design work, such as automotive, product design, or architecture, physical and virtual 3D models are created and re-created throughout the process. Virtual 3D models have several unique affordances that can help increase quality and reduce cost. Digital 3D data may be viewed on displays in a number of ways and may be classified as exocentric, planar, or egocentric. For any type, the viewing experience could be immersive as well. In the past, commercial visualization projects have put forward immersive or semi-immersive products like the CAVE® or the Fakespace™ Boom 3C, employing stereo goggles. However, in the design studio, we have found the value of untethered collaboration among participants to greatly outweigh any benefits from visual stereo effects. Design collaboration is a highly social activity and having to go to a special room and put on special equipment breaks the flow of normal design discussion. Also, within the immersive environment, common experiences like pointing at objects or jotting something down on a sketchpad are not possible.

For these reasons, we built the Boom Chameleon: a high-resolution touch sensitive LCD display panel tracked in 3D space by an articulated arm (see Figure 12, left and center). The Boom Chameleon serves three primary purposes. First, for the automotive design studio, it acts as an exocentric display that can be thought of as a virtual clay model at about a one fourth scale. Milling out a full-scale clay model is very expensive, costing more than \$1 million. Despite this high cost, this method of evaluating and modifying shape

*Figure 12. (Left to right): The Boom Chameleon, the Boom Chameleon as a 3D podium, and the Elumens Vision Dome (from Fitzmaurice et al., 2003).*



is still considered to be valuable. However, if a *virtual* clay model can reduce the number of iterations of full-scale models to be milled, the value of such a system would also be significant. A second purpose is to support distributed design. With the additional of a microphone and drawing/record/playback controls via the touch screen, the Boom Chameleon becomes a rich 3D annotation device (Tsang, Fitzmaurice, Kurtenbach, Kahn, & Buxton, 2002). Rich 3D messages with voice, explicit markup with a drawing tool, and implicit markup based on viewpoint, can be recorded and sent to the Portfolio Wall. Designers can pick up messages on the wall left for them offline by design managers who may even be at other physical locations. When synchronously collocated, the Boom Chameleon can serve its third main purpose; as a 3D podium (see Figure 12, center) with the display duplicated to a large wall-sized display for group viewing. By maintaining the 1:1 spatial mappings of moving around a physical object, the Boom Chameleon requires no significant training so design managers who do not normally use digital tools can easily drive the presentation and discussion around a virtual 3D model.

Although the Boom Chameleon serves the purpose of an exocentric display, the *Vision Dome* provides egocentric viewing ideal for “looking around” within a 3D model such as architectural spaces or automotive interiors. The Vision Dome is a 10-by-10 foot hemispherical concave display produced by Elumens (see Figure 12, right) and provides a sense of immersion because of its large size and curved surface. When viewing interior car designs, the enhanced sense of immersion provides a better sense of actually sitting inside the car. And because the user is not encumbered by stereoscopic hardware, body-language cues such as pointing, eye gaze direction, and eye contact during conversations are not obscured. On the other hand, the Vision Dome is not directly interactive. Therefore, as a controller, we added a 15-in. LCD with a touch-screen, again, running Portfolio Wall for both selecting objects as well as orienting them.

## 4.2. Portfolio Wall

Tying together the various terminals in the digital design studio is the Portfolio Wall, which can serve as an interface to several devices including the virtual art board. The primary interaction is simply to touch one of the tiled images to enlarge it to fill the screen (see Figure 13). Touching the screen again will reduce the image to reveal the tiles again. A marking menu is used to provide commands and actions. When an image is full screen, flicking to the right shows the next image. Flicking to the left shows the previous image. In this way, the Portfolio Wall can be used for impromptu presentations too. At the top of the screen are a number of user-defined tabs so that design managers can organize assets as needed. For example, each designer may have a tab or

*Figure 13. The Portfolio Wall (from Buxton, 2007).*



there may be a tab for each day of the week. On the right side of the screen, there is a compare area onto which images may be dragged. When the user has collected the images needed, the user can touch the compare area to enlarge it to full screen. Other simple marking menus provide control for videos and animations. For the tape drawing tool, users requested the additional abilities to compare designs, display related sketches and inspirational materials, and preview shaded surfaces. That is, they requested features to support the integration of related contextual content, to better fit into the overall design process. Part of this situation arises from the need to interact with others around the artifact, and this was best done around the art board.

When design artifacts are digital right from the creation stage, they can immediately become part of the digital workflow, being posted to the Portfolio Wall, the Boom Chameleon, or the Vision Dome. However, the collaborative aspects of the traditional art table and the art board are somewhat lost. The photograph in Figure 4 showing the cubicle space of a graphic designer was taken after hours at the Autodesk offices in Toronto. Notice how the monitor is turned off. This conveys one of the problems arising from the transition to digital processes that was related to our research group during a visit to General Motors in Detroit (Buxton, 2007). Design managers once had the ability to walk around the studio after hours to get an overview of what was going on by looking at the drawings on the drafting tables of all the designers. As is typical, all the monitors were off after hours or blanked when the designer was not presently working. The digital content being created was too virtualized. Impromptu informal discussions about designs and alternatives became difficult. And the implicit design status and history of a project, once nicely preserved by pasting things up on art boards, was lost.

These important parts of the creation and editing phases of the design process were poorly supported in the studios we visited. An obvious workaround



to this problem is to regularly print out images and post them on the traditional art boards. But in a hybrid studio, this approach can also create problems. A major American toy design studio related that they had frustrating line-ups at the wide-format printer before a design review session. Also, this approach obviously loses the benefits of the digital format of the data. So-called turntable animations are regularly created where the model slowly turns 360 degrees with specific lighting to convey the highlight qualities of the surfaces. These animations convey much more information than a still image printed on paper. Also, in the digital world, diverse images can be quickly compared and manipulated. Even 3D data sets could be posted and viewed on an electronic art board. To provide these features and to serve as both an awareness server (Dourish & Bly, 1992) and a status board, we created the Portfolio Wall prototype (Buxton, Fitzmaurice, Balakrishnan, & Kurtenbach, 2000) which was later productized and deployed to studios across the globe.

Conceptually, designers could throw images and videos or animations onto “the wall” at any time. Sketches, inspirational material, turntables, and 3D models could be posted and a copy would be made and kept by the system. We felt that it was important that the Portfolio Wall was considered to be an appliance, not a computer. That is, it only served this one purpose and it was always running. To this end, the program was always maximized and no operating system functions were shown. In fact, when we first showed our Microsoft Windows version, people did not notice that it was no longer running on IRIX.

After some user set time, it could go into “screensaver mode” and randomly display recent images and videos, or the random mode could be the primary usage. Depending on the hardware setup, interaction with the Portfolio Wall can be personal or public. In Detroit at a studio in General Motors with about 20 designers, they ran two Portfolio Walls. One was front projected, displayed on a very large 15-m wall (50 feet) so that all the designers could see it from anywhere in the studio. It was always in “screensaver mode” and continuously displayed recently posted imagery. In this way, the designers had a sense of what others were working on and mixed in were many inspirational (so-called lifestyle) images. Another version (as shown in Figure 11) ran on a 50-in. plasma display with a Matisse touch screen in the office of the design manager. At any time, the manager could get an overview of what was happening in the studio, and the status of the project as a whole. Finally, as content is normally never removed from the Portfolio Wall, it preserves and provides access to the evolution of a design. This emulates another studio practice of stacking art boards (which can be seen in Figure 2) to keep the project history.

The problem of interacting with the 2D and 3D content in the design studio also presents some unique challenges. Collaborating around large displays often involves lively discussion of new ideas and rapid turn-taking but

also careful evaluation of subtle features of the design and minipresentations. The flow of these conversations can easily be broken by obtuse interfaces, difficult to find data, or untrained users.

The restricted input on large displays—often just a touch screen—adds further difficulty to the problem. Once again, we find that interaction techniques designed for the desktop do not scale well to large displays, especially the typical expectations that a keyboard is present or mouse buttons are accessible. We developed a number of interaction techniques specifically designed for touch screen and/or pen-based input to help preserve the flow of the collaboration by reducing the “cost” of the interactions. We show tracking menus for 2D (Fitzmaurice, Khan, Pieké, Buxton, & Kurtenbach, 2003) and 3D, called SteeringWheels (Fitzmaurice, Matejka, Mordatch, Khan, & Kurtenbach, 2008), and a technique called HoverCam (Khan, Komalo, Stam, Fitzmaurice, & Kurtenbach, 2005) for simple 3D exterior navigation. Tracking menus are essentially a one-handed tool glass (Bier, Stone, Fishkin, Buxton, & Baudel, 1994) that works well for pen-based input as well as mouse and touch-screen. We also present the ViewCube (Khan, Mordatch, Fitzmaurice, Matejka, & Kurtenbach, 2008), an orientation tool, and ShowMotion (Burtnyk, Khan, Fitzmaurice, & Kurtenbach, 2006), a navigation and design review system. These tools are designed to complement each other, too (see Figure 14).

For 2D navigation, a simple zoom/pan tracking menu can be used (see Figure 6). For 3D, SteeringWheels are used; a task-based tracking menu for “outside” (with exocentric functions, Figure 15, left), “inside” (containing egocentric navigation functions, Figure 15, center), or “both” (see Figure 15, right).

**Figure 14.** SteeringWheels, ViewCube, and ShowMotion.

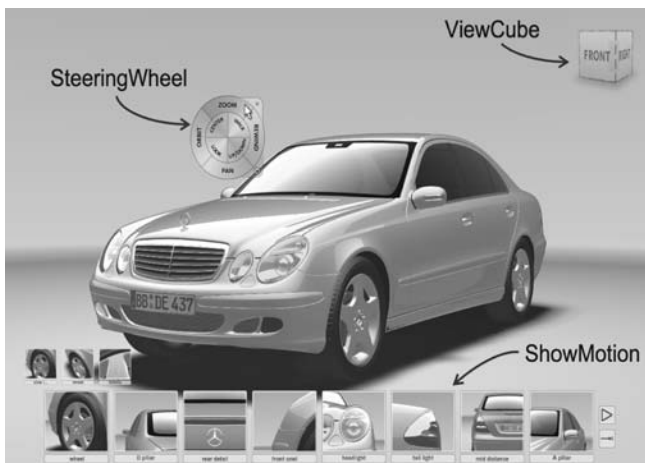


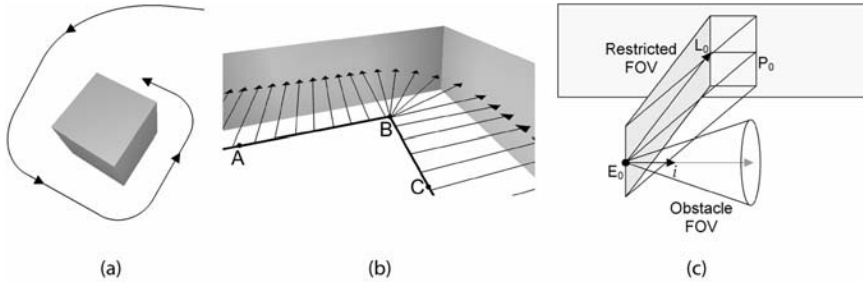
Figure 15. SteeringWheels (left) exterior navigation, (center) interior navigation, right (both).



The tracking menu approach helps to simplify the interaction by (a) working “in-place” so the tools are always at hand, (b) being always visible so the user can learn which group of functions are needed or may be helpful, and (c) each operation in the SteeringWheels is designed to be “safe,” that is, attempts to prevent error states and disorienting situations. For example, the zoom function prevents zooming out beyond some minimum size, so the model will not disappear completely. A more complex example would be the orbit tool. Orbiting a model that is roughly spherical in shape will work as expected but revolving about a particularly oblong shape may end up with the “eye” inside the model or very far away from the model. To prevent these and other types of exocentric navigation problems, we developed a navigation tool specifically for object inspection operated by a single input (ideal for touch screens) called HoverCam.

Moving around in an exocentric way can be fairly complex. Typically, desktop 3D software applications provide zoom, pan, and orbit functions to accomplish the basic substeps needed to navigate around the outside of a 3D object. The user must interleave these basic tasks to accomplish larger goals of moving from the front of the car to the side, for example. Many applications map the three basic commands of zooming, panning and orbiting to the buttons on a three-button mouse, or they could be presented on a tracking menu. However, when the task is known to be surface inspection, it would be preferred to have a technique that could accomplish the higher level navigation goals with low dimensional input. This was the goal of our HoverCam project. By using simple collision detection in restricted fields of view, zooming, panning, and orbiting can be combined to provide the needed camera motion with only two dimensions of input (see Figure 16). The HoverCam interaction technique greatly simplifies exocentric navigation for object inspection and works well on touch-screens and even mice with only one button. So, when appropriate, the orbit command on the Steering Wheels could use the HoverCam algorithm.

**Figure 16.** (a) HoverCam camera motion path approaching and turning to follow the surface of the object, (b) HoverCam camera motion path and camera look-at direction in an “interior” concave shape, and (c) the HoverCam algorithm showing the Restricted Field of View (FOV) and the Obstacle FOV looking for obstructions to help turn the camera (from Khan et al., 2005).



The ViewCube (see Figure 14) is a cube-shaped widget placed in a corner of the screen that serves as a proxy object for the 3D scene. In the design of the widget, we applied the edicts of direct manipulation: (a) continuous representation of the object of interest, (b) physical actions or labeled button presses instead of complex syntax, and (c) rapid incremental reversible operations whose impact on the object of interest is immediately visible. The widget has selectable pieces and spatially arranges the 26 possible views (8 corners, 12 edges, 6 faces—see Figure 14).

Clicking on a piece of the ViewCube selects the corresponding view and smoothly animates the camera position to achieve that view (Figure 17, left). The click regions are enlarged at the edges of the widget (Figure 17, right) so users can more easily select the smaller pieces. Dragging on the ViewCube also rotates the scene and view snapping makes it easy to achieve one of the fixed views. When navigating using other tools, the ViewCube rotates to ambiently report the current scene orientation.

**Figure 17.** (Left) Before and after clicking the highlighted corner. (Right) Expanded hit areas for boundary buttons. Clicking anywhere within the green regions will select the corresponding button.



Clicking on a piece of the ViewCube selects the corresponding view and smoothly animates the camera position to achieve that view (Figure 17, left). The click regions are enlarged at the edges of the widget (Figure 17, right) so users can more easily select the smaller pieces. Dragging on the ViewCube also rotates the scene and view snapping makes it easy to achieve one of the fixed views. When navigating using other tools, the ViewCube rotates to ambiently report the current scene orientation.

ShowMotion (see Figure 14) attempts to simplify 3D navigation even further by presenting a number of thumbnails representing short camera animations around the 3D model. The user can choose to “go there” to jump directly to that position within the 3D scene or they can choose to “play” the associated shot and see a camera animation (typically from 3 to 10 sec) ending at the position shown in the thumbnail. Shots can be grouped into sets to help visually organize related shots. The upfront cost of this technique is that the designer must pre-author the shots. The designer can choose from a list of eight predefined shot types and we have a very simple interface where shot parameters can be modified.

As the literature suggests, motion cues are useful in 3D object assessment (Todd, 1998, 2004). In particular, motion cues are extremely important in the perception of subtle shapes and are of great value to aesthetic design reviews. For this reason, as well as to avoid time-consuming and visually jarring manual navigation, we use motion instead of static images as the basis of composing and conducting a review. The core idea is that design review content should be “alive” (i.e., in motion) most of the time. Obviously, using too much motion could be problematic but we have discovered that even small motions, such as a slow camera zoom-in, provides the necessary 3D sensation without producing a visually jarring and distracting experience.

Our system emphasizes a “click to navigate” design that is intended to remove the need for reviewers to understand and control typical high degree of freedom (DOF) 3D camera controls such as tumble/pan/zoom controls by dragging or navigation via six DOF devices. For example, rather than navigating via these types of controls to a particular viewpoint, the user finds a shot corresponding to the viewpoint and goes to that viewpoint by a simple single click on its thumbnail.

Another benefit of the simple “click to navigate” approach is that this allows nonpresenters to be successful in controlling the system and inspecting the design. We have observed that many formal design review presentation meetings break up into situations where members of the audience (other designers and managers) have the opportunity to interact with the system while the presenter is busy talking to others. In this case, we have observed that many audience members are unable to successfully use the traditional navigation controls and quickly give up, most likely leaving the system at an awk-

ward and low value viewpoint. In contrast, our intention is that audience members will easily understand how to get to certain design viewpoints by watching the presenter and successfully operating the system themselves. A final benefit of this simple navigation scheme is that because the system is never displaying awkward viewpoints or jarring visuals no matter who is controlling it, the presenter's design is always portrayed in a polished manner thus enhancing the impact of the presentation and reviewer perception of the design. Adding cinematic effects such as "fade to black" as transitions between shots improves the overall pacing and visual quality of the experience.

To summarize, the SteeringWheels, HoverCam, ViewCube, and ShowMotion techniques and systems are all carefully designed to assist both novice and expert users when interacting with 2D and 3D content. This work represents a significant amount of research and evaluation including dozens of usability studies with users from several types of design as well as several formal experiments. We are confident that these features greatly improve the flow of collaboration and presentation in design studio settings.

### 4.3. Sketchboard

Two factors lead us to investigate further the edit/collaboration aspect of meetings in the design studio. First, although we had a wide variety of terminals and large displays in our digital studio prototype environment, we had not captured an important part of the art board purpose. Designers related to us that art boards are not simply collections of design variations, related work, and inspirational material. The art board *itself* is also carefully designed. That is, when brought into a meeting room for a designer to present their work, the size, placement, and position of all the materials are carefully arranged to help tell the story about the design. Second, brainstorming and decision-making meetings involve significant rearrangement, note taking, sketching over artwork, and comparison. Despite the success and flexibility of Portfolio Wall to be used in several ways for a number of design activities, several additional key features were needed. We considered how we could integrate high-quality sketching and more flexible asset arrangement in a meeting setting, and called this project *Sketchboard* (see Figure 18).

The scenario we were interested in investigating was set in an environment of TabletPCs, laptops, large displays, computer workstations, and digital assets such as images and 3D models. We have observed in our own workplace several attendees bringing their laptops to a meeting and taking turns presenting materials via the projection system simply by passing the projector input cable around. Essentially this style of usage has emerged from the affordances and economics of projection systems and PC technology. For design collaboration meetings however, this overhead noticeably breaks the flow of discus-

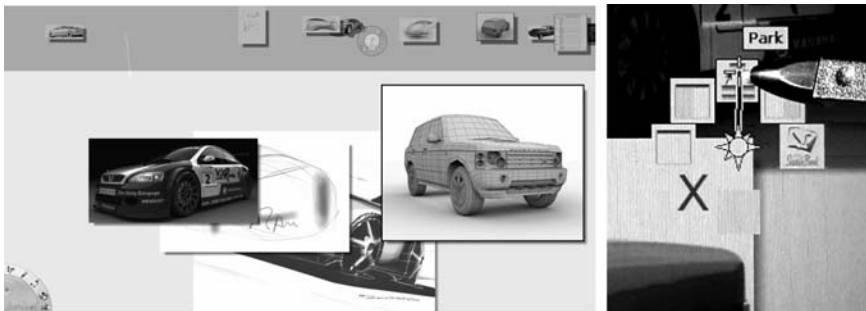
sion and ideas as well as the sharing of materials. Our goal was to create a system that would not impede meeting workflow but rather, would enhance it.

We implemented a client/server system to synchronize changes being made by a number of participants. A central server would manage the asset database and the communication to the client wireless TabletPCs. The server interface would always be full screen on a large display. Each participant in the meeting would have the client version that included additional functionality for drawing on the board, SteeringWheels for moving, scaling, or orbiting assets, and quick transfer back and forth to Sketchbook for high-quality pressure-sensitive sketching.

The Sketchboard interface (see Figure 19, left) supports a nontiled display of images, animations, and 3D models. At the top of the screen we have a darkened area we call the “parking lot.” Like zoomscapes (Guimbretière, Stone, & Winograd, 2001), when an object is moved into the parking lot, it is automatically resized to fit in that region. Alternatively, a small command triangle is shown over each object when the cursor is nearby to access a marking menu where a park command can be instantly given starting a short animated transition of the object up to the parking lot (Figure 19, right). Flicking down on the marking menu on a parked object “unparks” the object, restoring it to its original position on the board. This serves to support “putting away” some objects while having them readily available to add back to the discussion, that is, the main display area. Also, by employing the marking menu to park/unpark instead of dragging, maintains the original positioning and scale information that could have been important when restoring. Even seeing which objects have been “parked” helps convey decisions that have been made during the meeting.

Other commands in the marking menu are enlarge left, enlarge right (for making comparisons; see Figure 20, left), full screen (to maximize a single ob-

*Figure 19.* (Left) Sketchboard interface; (right) marking menu with user selecting “park” with the pen.



**Figure 20.** Sketchboard (left) Compare, (middle) maximize, (right) open in Sketchbook Pro.



ject; see Figure 20, middle), delete an object (the red “X”), “restore” (to unmaximize and return to the board display), and Open in Sketchbook (on the local TabletPC for annotation or creating new sketches; see Figure 20, right). Note that although objects may be maximized on the large display, the client running on the Tablet PC always shows the art board view. For working directly on the board (see Figure 21), the user has the zoom/pan tracking menu tool, a drawing tool, a color chooser, an eraser tool, and a viewing option to (a) view entire board (see Figure 14; TabletPC on the right) or (b) fit board to height, with scroll bar (see Figure 21).

An exception is when a user chooses to open an image locally in Sketchbook Pro. In this case, the image is downloaded to the TabletPC over the wireless network and Sketchbook Pro is launched, full screen, with that image (see Figure 20, right). To help differentiate which application the user is seeing, we chose to make the bottom left corner command palette yellow for Sketchboard and blue for Sketchbook. When the user has finished sketching,

**Figure 21.** Working on Sketchboard from the TabletPC. (Left) using tracking menu; (right) drawing directly on the board (via the TabletPC).





two choices are provided to support public or private usage. If the user had been sketching ideas for later use or taking private notes, the user can save locally to their own computer. Otherwise, to return a modified sketch to the board, the user can “save and return to Sketchboard,” which will transfer the file back to the database and broadcast the change to all participants. In both cases, Sketchbook closes and Sketchboard becomes visible again. Finally, an import option lets users add imagery to Sketchboard from their local machine or the network. Sketchboard automatically parks new items as they are added to the board. This allows participants to queue up items without disrupting the flow of the meeting.

All changes during a meeting are implicitly tracked allowing “rewind” and general temporal browsing through past meetings. At the end of each meeting, explicit markings are made to easily return to the beginning or ending of any meeting. Although this was originally an artifact of our client/server architecture, we found it useful to have these capabilities, especially to start a new meeting where the last one left off. Also, deletions were simply tagged as such so Sketchboard always had access to material that had been removed.

We believe that Sketchboard was conceptually simply enough not to impede the flow of the meeting, yet rich enough to support the usage scenarios we found to be valuable during the edit/collaboration phase of design. Sketchboard supports visual conversations by allowing rapid turn-taking, visual manipulation, and annotation. We ran an exploratory study with a subset of a design team from a major automotive manufacturing company. Four users, including one design manager, visited our lab and were shown the system. We had prepared what we felt would be a typical data set and spent an hour demonstrating the features and usage scenarios, as we described previously. The users spent a full day with us using the system and working through possible scenarios and requirements, and provided us with many useful insights, suggestions, and feedback. They reported that they would be happy to use the prototype as is and were looking forward to trying it in practice. As an outcome, four main points were raised:

- *Decision Tracking:* The collaboration phase of design consumed most of the time of a given project for this studio. Over this lengthy period, it was difficult or impossible to track the evolution of the design. A major problem the design teams were currently having was to definitively know who made a specific design decision and when. Knowing what decisions were taken during a meeting was not currently being captured and this was considered to be a serious flaw in their current practices. Also, when the team would meet for their next weekly meeting, a common problem would be recalling what decisions were made, and equally important, why. The designers said they would sometimes wonder if they were in

fact going back to some previously rejected variation. We suggested that perhaps the decisions could be noted on the board in a reserved color, like red. Although they agreed this may help, they wanted an even stronger sign-off procedure integrated into the system.

- *“Drilling Down:”* For 3D models, the designer manager felt that the model should represent a container of all the related data including Excel spreadsheets of part numbers, and so on. Also, he felt that design variation of known parts would be helpful. For example, flicking a marking menu on a wheel would load in another 3D model of a wheel from their database. Also, launching a Portfolio Wall of related objects was also requested.
- *Accessing Historical or Competitive Data:* The designers felt it would be useful to call up various previous cars models that were well known or perhaps came to mind based on the data currently being viewed. In brainstorming, it would be nice to have easy access to, for example, “classics like the ’67 Corvette.” Similarly, having quick access to competitive models or other objects in their database was desired. In short, some type of lightweight database search would be helpful.
- *Relationship to Portfolio Wall:* This company had standardized on Portfolio Wall across their studios, as our company had productized our original prototype, and they were interested in how these two systems may work together.

Although the issues raised were all reasonable, we were pleased that the designers all believed Sketchboard would be immediately useful for them, and that all of the features discussed still related to collaboration, instead of mixing into other phases of the design process. That is, this validated our belief that collaboration was a significant enough design process activity to warrant a strong-specific solution instead of attempting to “make do” with a weak-general solution.

#### 4.4. Viz Studio

Although our test users did not raise this as an issue, we felt that our Sketchboard implementation in the lab felt somewhat constrained. In reviewing Figure 18, notice that despite the large display being approximately 14 feet long, the number of images displayed simultaneously was small. This may have been because of the combination of our relatively low display resolution (2048 × 768 pixels) and the overall physical size. The Sketchboard evaluation also led to requests for additional layering of data and images, perhaps because the users felt constrained as well but did not express the solution in terms of having a larger display with better fidelity. Generally, from discussing the potential of a

Figure 18. Sketchboard on a number of TabletPCs and a large displays.



tool such as Sketchboard with a target user group, we felt that many more images and models would be needed to be displayed in a single session. We concluded that this issue was a significant factor to maintaining flow during a collaborative design meeting, and so, we investigated larger configurations and the issues that may arise along with our presumed benefits.

Based on our experiences with large displays and the possibilities of enhancing design discussions, Alias (now Autodesk) invested in the construction of a corporate briefing center called the Visualization Studio, or Viz Studio (Fitzmaurice, Khan, Kurtenbach, & Binks, 2005), at our corporate headquarters in Toronto (see Figure 22). This unique meeting facility is designed to support digital visual communication and collaboration. Recalling the design artifact life cycle (see Figure 3), *communication* and *presentation* represent important stages of the design process and the creation of the Viz Studio set the stage for us to further understand the benefits and challenges of such an environment on the design process.

In the conceptual design phase for the Viz Studio, we considered the overall user experience. The target users would be design studio managers and senior designers. The target experience would be for visitors to learn how our proposed design review tools would interact and for them to teach us how their design processes currently work. For our target usage of the space, some of the stages of a visit would include arrival and initial impression, work requirements, all day meeting needs, overall comfort, social needs, departure and departure feelings, and so on.

Figure 22. The Visualization Studio in Toronto (from Fitzmaurice et al., 2005).



In *Computers as Theatre*, Laurel (1993) proposed a theatre metaphor for designing interactions with digital information and some of these concepts were included. The premise of *The Experience Economy* (Pine & Gilmore, 1999) considers a visitors' total experience. Combining this metaphor with the experience approach and large-display technology has yielded a facility with many cinematic and theatrical characteristics. The main front wall uses two projectors (Barco SIM6) with a total maximum resolution of  $3,200 \times 1,200$ . This setup and viewing is akin to a large, high-resolution movie theater. An additional wall and projector flank single projectors on both sides of the main front wall. This makes for a total of  $64 \times 9$  feet of display space with  $7,680 \times 1,024$  pixels having six projectors set at  $1,280 \times 1,024$  pixel resolution.

We modified our Sketchboard application to use the Chromium library, derived from the Stanford Graphics Lab WireGL project (Humphreys, Eldridge, Buck, Stoll, Everett, & Hanrahan, 2001), to run our OpenGL program across multiple machines. Unfortunately this reduced our frame rate to only four or five frames per second. However, the result of seeing Sketchboard running across a seventy foot stretch (we used two flanking walls on each side of the main display) was still impressive.

### Frisbee

Another problem with Sketchboard that we observed and was noted by users was that there were often times where people were up at the screen explaining things and it was frustrating not to be able to use direct manipulation to effect changes. Our large screen display was simple front projection with no direct input. Turning to the TabletPC could break the flow of a person's message or explanation depending on the types of modification to the design being discussed. As such, we began to investigate how users could work at arm's length on a very large display manipulating many objects around the large board. We also expected that with such a large display, more than one

person may be making changes simultaneously on different parts of the screen, working directly on the display or at a distance. Finally, we wanted a solution that reflects the characteristics and workflow of a traditional design studio. This led us to the following design principles (adapted from Khan, Fitzmaurice, Almeida, Burtnyk, & Kurtenbach, 2004).

- *Support multiple concurrent users.* The operations performed by one user should not unexpectedly affect the local workspace of another concurrent user.
- *Minimize visual disruption while working.* The workspace should remain as static as possible so as to minimize the disruption to viewers who may be looking at areas of the display, unknown to the user making concurrent modifications.
- *Maintain visual persistence of space.* The workspace should remain as static as possible so that when users re-enter the studio, spatial memory will help them to find specific areas or images as with real art boards.
- *Minimize physical travel.* The distance that a user has to move in the physical space should be minimized, regardless of their location or the operation to be performed.

To meet these goals, we developed an interaction technique we call the *frisbee* (see Figure 23). The frisbee technique provides a portal to another part of the display allowing the user to see and interact with disjoint or distant spaces.

*Figure 23.* Using the Frisbee with Sketchboard on a 20-foot display (from Khan et al., 2004). *Note.* The frisbee consists of a telescope and a target. The target pink ring (top right) can be panned and scaled by using controls, under the users hand, on the pink ring in the telescope (bottom left).



It consists of two main components: a “telescope” and “target” (see Figure 24).

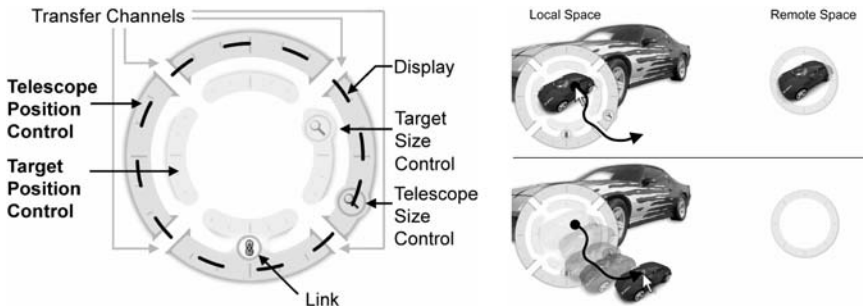
The telescope provides viewing and manipulation at arm’s length of the contents within the target. The target’s boundary is visible at its remote location giving the user a sense of where the target is. Its visibility also gives other users an awareness of the user’s remote presence within the large display space. This is particularly important since the user may be manipulating the data but is not standing physically close to the remote data.

The telescope consists of three zones: the blue outer ring contains the telescope controls, the pink inner ring has the target controls, and the region within the pink inner ring is the display area (see Figure 24, left). The telescope controls allow positioning and sizing of the telescope itself. The target controls allow positioning and sizing of the target. The display allows viewing of, and interaction with, the contents within the target.

When the user interacts with the data in the inner display region, input events are translated as if the user were operating directly on the content within the target area of the large display. For example, in our sample application the user can select an image object within the display. Moving the image within the display causes the object to move at the actual target location on the board. The frisbee can also be used to transfer objects into the local space or vice versa. Grabbing an object and dragging it through a *transfer channel* causes it to be moved to the area of the board outside the frisbee, namely the local space (see Figure 24, right).

Though still only in the prototype phase, many other space management and workflow functions are available using the frisbee (see Khan, et al., 2004) making this technique quite useful for large display work.

**Figure 24.** (Left) The Telescope contains controls for a “position control” and a “remote control” ring with four “transfer channels” along the perimeter (from Khan, et al., 2004). (Right) The user can click on a remote object within the telescope display and drag it through a transfer channel to the local space.



## Spotlight

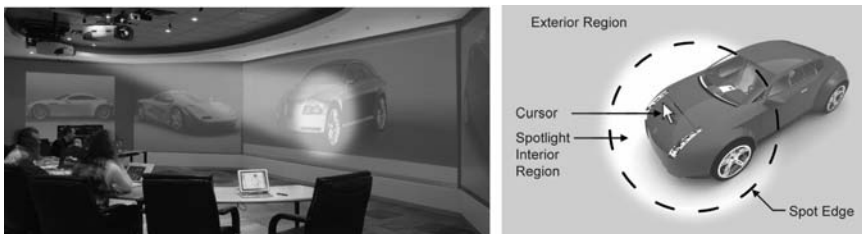
Although the very large display in the Viz Studio solved many problems, we also noticed the effort needed to direct the attention of the participants to a specific area of the display. Even though the presenter may point at an area being discussed, some audience members would invariably be looking elsewhere and not notice the cue. The typical “shaking the cursor” to attract attention also fails as it is small and often the same white color as the material around it. To overcome this problem during collaboration and presentation sessions, we developed a software spotlight (see Figure 25).

The spotlight technique (Khan, Matejka, Fitzmaurice, & Kurtenbach, 2005) directs the attention of audience members to a specific part of the display simply by visually damping most of the display. Like a real spotlight, a darkened stage is used and the spotlight illuminates the objects of interest. The spotlight can be moved to point at other objects and can be resized to include more or less space. Once invoked, the technique begins by darkening the display content (by about 75%) except for a large circular region around the current cursor position. Unlike a real spotlight, while the spotlight is moving, the darkened region around the spotlight is brightened up (to about 50%), letting the presenter more easily see the intended destination. When the spotlight stops moving, there is a short dwell time and the screen slowly darkens again to 75%. The spotlight is a tracking menu following the cursor as the presenter moves it (see Figure 25, right). However, the cursor can move around freely within the spotlight region to point at smaller targets.

We found that dimming the brightness of the screen had a dramatic effect on both the room and the content.

The lighting in the room changed from an ambient white glow (from the scattering of light from six powerful projectors) to a pleasing, calm, darkened environment reminiscent of a theatre. Images in the spotlight appeared sharper and with better color contrast (due to the reduced scattering of light). Due to the

**Figure 25.** (Left) The Spotlight technique on a large wall-sized display (enhanced image). (Right) Spotlight components (exterior region, spot edge, spotlight interior region, cursor; from Khan, et al., 2005).



front projection setup, our virtual spotlight shared many of the properties of a real spotlight. (Khan, et al., 2005, p. 793)

#### 4.5. Summary

To summarize the collaboration section of this article, we presented our digital design studio trial environment with terminals to help communicate 3D data via their physical affordances: the Boom Chameleon (exocentric display), Portfolio Wall (virtual art board), and Vision Dome (egocentric display). In particular, the Portfolio Wall also served as a common interface across the studio and we explained the designs and design rationale for interaction techniques: SteeringWheels (freeform navigation), HoverCam (object inspection), ViewCube (orientation), and ShowMotion (pre-authored navigation). Pushing beyond the constraints of Portfolio Wall, we built the “non-tiled” version and further extended it specifically for collaboration. All of these experiences informed our decisions for creating a real working space called the Viz Studio, which lead us to solutions for room-sized displays like the frisbee and the spotlight systems.

The complexity of the digital design studio and the numerous systems and interactions used reflects both the intricacies of the social aspects of the studio as well as the fundamental size of the task. At the same time, the value of many very large displays is clear. Design is a visual process, and both hardware and software solutions can be used to highlight the beautiful sketches, drawings, models, and layouts that these visual artists create.

### 5. DESIGN ARTIFACT LIFE CYCLE: PRESENTATION

As mentioned earlier, presentation is an important part of the design process. Presentations happen informally in the creation and editing phase, and this type of presentation is supported well by the Portfolio Wall. During collaboration, specialized devices like the 3D podium, driven by the Boom Chameleon duplicated to a large display, or the Vision Dome, work well to present and discuss exterior or interior design issues. Although Sketchboard was designed for collaboration, it could also be used to deliver dynamic (i.e., not preplanned) nonlinear presentations. However, toward the end of the design process, more formal presentations are given to management and senior management. This is the designer’s opportunity to carefully craft a presentation to communicate the key design concepts as well as to establish their identity to the senior management for possible promotion within the organization, as we have learned in our studies. The success of the presentation now depends not only on the design skills of the presenter but on their presentation skills, too.



The first author of this paper spent 4 months with design students at the Ontario College of Art and Design (OCAD) trying to discover the challenges students were facing as designers who were about to leave the education system and begin practice as industrial designers, graphics designers, and interior/architecture designers. Based on the most cited student concern, a term project was started to design an environment to help designers improve their presentation skills. The action research method was used, which emerged from social science, group dynamics, and organizational behavior, and is best summarized as “research with people” instead of “research on people.” Action research assumes that complex social processes cannot be reduced for meaningful study (Baskerville & Stage, 1996). As such, viable solutions must be a product of the process. This method itself is collaborative and participatory in nature where the design students became researchers to better understand the problem being examined (Lau, 1999). The outcome of the study was the Presentation Room system (see Figure 26).

The augmentations to the room are meant to enhance both the delivery and experience of the presentation. Equipping the speaker with additional apparatus could impede the flow of the presentation, so our approach is to augment the space, as was done in our previously discussed systems. We take the Krueger (1993) and Coen (1998) approach with a “come as you are” interface.

Charismatic people who bring their designs to life are often very animated, making eye contact with audience members, varying the pitch of their voice, and pacing the narrative of the presentation to a climax point. Poor speakers typically stand very still, speak in a monotone voice, and simply read volumes of text from the slides to the audience. Communication is the main objective of any presentation and our goals are driven by this: (a) Ubiquitous: Augment the space, not the speaker. (b) Enhanced delivery enhances content: We address the presentation experience, such as presenter performance and content context. (c) Walk-up-and-use: The interface should be simple to control and require little training. (d) Heads-up: Our goal is to help the presenter to engage the audience by being untethered and able to move about freely, prevent divided attention, facing audience members, making eye contact, and so on.

*Figure 26. A panoramic (composite) image of the Presentation Room.*

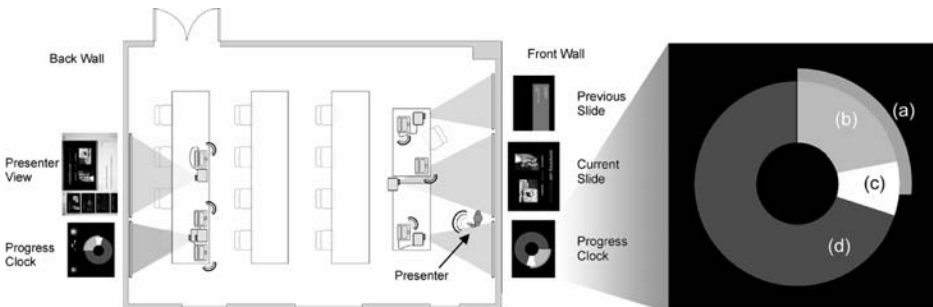


Given these guidelines, we developed the Presentation Room (see Figure 27). The physical room used in the study is rectangular and measures approximately 7 meters by 10 meters. Projected on the Front wall is the current slide in the center flanked by the previous slide on the left and the *Progress Clock* on the right. On the back wall, the PowerPoint Presenter's View is displayed centrally while the Progress Clock is projected in the back corner of the room. A number of designers may be seated in rows facing front toward the presenter.

A number of researchers have investigated the design space and usage of ambient displays. The early work of Ishii and Ullmer's (1997) ambientRoom noted the value of foreground and background interactions. Redström, Skog, and Hallnäs (2000) described issues around placement and design of ambient displays. Matthews, Dey, Mankoff, Carter, and Rattenbury (2004) and Baudisch, Good, Bellotti, and Schraedley (2002) described the relationship of peripheral displays to user attention. The relationship between secondary displays and timing or pacing in an interaction is discussed in Mamykina, Mynatt, and Terry (2001).

The two screens at the back of the room act as a form of feedback from the audience to the presenter, without the audience actively controlling anything. The three displays at the front of the room give the audience a frame of reference as to how far along the presentation is and provides a previously shown slide to catch up on any missed concepts. The placement of screens at the back of the room encourages the speaker to better engage the audience. The speaker is guided into making eye contact with audience and will naturally position himself or herself to face the audience when facing the feedback screens. Compare this to the traditional setup of the slides being shown only on the main audience screen, or on the main screen and mirrored onto a podium screen. In both traditional situations, the speaker is actually encouraged to look and face away from the audience.

**Figure 27.** Presentation Room schematic. Inset: Components of the Progress Clock: (a) elapsed time, (b) slides already displayed, (c) current slide, (d) slides not yet seen.



The progress clock helps the audience and the presenter to have a sense of how far along the presentation is, both in terms of how many slides are yet to come and how much time is remaining. Another feature that supports even pacing of a presentation is the outer ring representing the elapsed time (shown in Figure 27(a)) operating like a stopwatch. As the time elapses, the orange ring is continuously updated. This can be helpful in gauging if the presenter is ahead of time or behind, providing pacing awareness to everyone who affects the presentation flow.

Overall, this gave the appearance that the speakers knew their material well and were aware of the pacing that the audience expected. The audience found the additional displays to be somewhat empowering as well. One audience member noted that when the speaker was clearly ahead of time (based on looking at the progress clock), he felt it was alright to ask a question at that time, i.e. that it would not be an unwelcome delay because there was extra time. Another audience member found the progress clock to be very motivating to stay attentive to “make it through a presentation,” as it explicitly shows the progression of the talk and so, gave her an indication of how much more effort would be required of her. Also, the progress clock seems to elicit respect from the presenter for the time of the audience members, which is an important factor in delivering design review presentations to senior management.

We have presented an augmented classroom that employs both primary and ambient displays for both the presenter and the audience, emulating a design review experience. In particular, the heads-up design principle and the progress clock were found to be quite helpful. At the end of the 4 months, the student-researchers were exposed to several empirical techniques that can be used as tools in their commercial design work, which may increase their confidence when presenting their designs to future clients and managers.

Clearly we are only beginning to explore the social and technological needs of the formal presentation phase of design. Furthermore, we have only examined internal design presentations. Most likely, Head of Design presentations to external clients will be significantly different. Anecdotally, we have been told by designers that the styles of such presentations vary significantly based on the personality of the presenter. Still, the final presentation of a design project is of critical importance to the success of the design and warrants further study.

## 6. CONCLUSIONS

By looking at the roles and activities surrounding the design studio environment over the past decade, we have had a rich problem domain to investigate and explore the possibilities of future ubiquitous multidisplay environments. Many fruitful research projects have resulted and we are happy to

have had impact on designers in the field. We have examined the creation, collaboration, and presentation aspects of the design process and have touched upon many areas of interaction design, environment design, as well as studio design.

As mentioned in the first section, the roles and activities do not seem to have changed much, yet the tools and tasks have significantly changed because of computerization of the process. The benefits of digitization are so great that traditional non-digital studios are no longer viable. On the other hand, as the digital design process is still incomplete, many challenges still exist.

The design process is a very creative intuition-based exercise quite different from technical processes. As such, we feel that a key concept against which to judge any particular component is flow. Maintaining flow in expressing design concepts, collaborating around design artifacts, and discussing, presenting, and reviewing designs is paramount. This is also why “bigger is better” in that as much contextual material as possible should be easily accessible. Over the course of our investigations, our displays became larger and larger. Note that this does not equate to a call for more pixels as we find the high-resolution projectors of the day to be sufficient without vertical tiling.

Techniques that impede flow for this highly social activity include immersive technologies, tethered devices, and uncomfortable interactions. It has often been suggested that the popular “Minority Report” standing and hand-waving interaction style will become important. However, it was this very concept that led us to the Sketchboard paradigm where participants really just want to sit down and let someone else “stand at the board”; a belief that was validated by our users. Another ongoing workflow that is often strongly suggested to be important is to support multiple people working directly on the large display simultaneously. However, even on the very large displays in our Viz Studio, we have again found that people are not so eager to do so much work on the board when they can more comfortably achieve the same end while sitting at the desk and drawing on the Tablet PC. The social protocols of polite turn-taking still seem to overpower any strong need to “interrupt” before the other presenter is finished.

It is certain that the advent of digital design studios will lead to still more distributed design, including more distributed critiques, giving rise to the difficulties we all experience now with remote collaboration for knowledge-work. Perhaps this fact has prompted many customers and designers to relate their worries about remote collaboration. However, until the “simple” collocated collaboration is well understood, it seems to be putting the cart before the horse to deeply examine remote teamwork. During the design of many of our systems and techniques, we have not attempted to consider remote usage. We believe there is still much to understand and improve for face-to-face meetings.

Ultimately, we believe that physical artifacts have enormous benefits and that a hybrid digital-physical studio will endure. Sampling and synthesis techniques will *both* continue to provide valuable feedback to designers (Fitzmaurice, Balakrishnan, & Kurtenbach, 1999) especially in the creation of physical products, automotive design, and architecture.

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## NOTES

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## REFERENCES

- Balakrishnan, R., Fitzmaurice, G., Kurtenbach, G., & Buxton, B. (1999). Digital tape drawing. *Proceedings of UIST 1999—The ACM Symposium on User Interface Software and Technology*. New York: ACM.
- Baskerville, R., & Stage, J. (1996). Controlling prototype development through risk analysis. *MIS Quarterly*, 20(4), 481–504.
- Baudisch, P., Good, N., Bellotti, V., & Schraedley, P. (2002). Keeping things in context: A comparative evaluation of focus plus context screens, overviews, and zooming. *Proceedings of CHI 2002, Minneapolis, MN*. New York: ACM.
- Bier, E. A., Stone, M. C., Fishkin, K., Buxton, W., & Baudel, T. (1994). A taxonomy of see-through tools. *Proceedings of the ACM CHI 1994*. New York: ACM.
- Burtnyk, N., Khan, A., Fitzmaurice, G., & Kurtenbach, G. (2006). ShowMotion: Camera motion based 3D design review. *I3D 2006 Proceedings, ACM Symposium on Interactive 3D Graphics and Games*. New York: ACM.
- Buxton, B. (2007). *Sketching user experience: Getting the design right and the right design* (pp. 162–165). San Francisco: Morgan Kaufmann.
- Buxton, B., Fitzmaurice, G., Balakrishnan, R., & Kurtenbach, G. (2000). Large displays in automotive design. *IEEE Computer Graphics and Applications*, 2, 68–75.
- Coen, M. H. (1998). Design principles for intelligent environments. *Proceedings of the National Conference on Artificial Intelligence. American Association for Artificial Intelligence, AAAI '98*.

- Dourish, P., & Bly, S. (1992). Portholes: Supporting awareness in a distributed work group. *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems*. New York: ACM Press.
- Fitzmaurice, G., Balakrishnan, R., & Kurtenbach, G. (1999). Sampling, synthesis, and input devices. *Communications of the ACM*, 42(8), 54–63.
- Fitzmaurice, G., Khan, A., Buxton, B., Kurtenbach, G., & Balakrishnan, R. (2003). Sentient data access via a diverse society of devices. *ACM Queue*, pp. 53–62.
- Fitzmaurice, G., Khan, A., Kurtenbach, G., & Binks, G. (2005). Cinematic meeting facilities using large displays. *IEEE Computer Graphics & Applications*, 25(4), 17–21.
- Fitzmaurice, G., Khan, A., Pieké, R., Buxton, B., & Kurtenbach, G. (2003). Tracking menus. *UIST 2003 Proceedings, ACM Symposium on User Interface Software & Technology*. New York: ACM.
- Fitzmaurice, G., Matejka, J., Mordatch, I., Khan, A., & Kurtenbach, G. (2008). Safe 3D navigation. *I3D 2008 Proceedings, ACM Symposium on Interactive 3D Graphics and Games*. New York: ACM.
- Grossman, T., Balakrishnan, R., Kurtenbach, G., Fitzmaurice, G., Khan, A., & Buxton, B. (2001). Interaction techniques for 3D modeling on large displays. *Proceedings of I3D 2001—The ACM Symposium on Interactive 3D Graphics*. New York: ACM.
- Grossman, T., Balakrishnan, R., Kurtenbach, G., Fitzmaurice, G., Khan, A., & Buxton, B. (2002). Creating principal 3D curves with digital tape drawing. *ACM CHI 2002 Conference on Human Factors in Computing Systems*. New York: ACM.
- Guimbretière, F., Stone, M., & Winograd, T. (2001). Fluid interaction with high-resolution wall-size displays. *Proceedings of ACM UIST 2001*. New York: ACM.
- Humphreys, G., Eldridge, M., Buck, I., Stoll, G., Everett, M., & Hanrahan, P. (2001). WireGL: A scalable graphics system for clusters. *Proceedings of SIGGRAPH 2001*. New York: ACM.
- Ishii, H., & Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.
- Kaptelinin, V., & Czerwinski, M. (Eds.). (2007). *Beyond the desktop metaphor: Designing integrated digital work environments*. Cambridge, MA: MIT Press.
- Khan, A., Fitzmaurice, G., Almeida, D., Burtnyk, N., & Kurtenbach, G. (2004). A remote control interface for large displays. *UIST 2004 Proceedings, ACM Symposium on User Interface Software & Technology*. New York: ACM.
- Khan, A., Komalo, B., Stam, J., Fitzmaurice, G., & Kurtenbach, G. (2005). HoverCam: Interactive 3D navigation for proximal object inspection. *I3D 2005 Proceedings ACM Symposium on Interactive 3D Graphics*. New York: ACM.
- Khan, A., Matejka, J., Fitzmaurice, G., & Kurtenbach, G. (2005). Spotlight: Directing users' attention on large displays. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.
- Khan, A., Mordatch, I., Fitzmaurice, G., Matejka, J., & Kurtenbach, G. (2008). ViewCube: A 3D orientation indicator and controller. *I3D 2008 Proceedings, ACM Symposium on Interactive 3D Graphics and Games*. New York: ACM.
- Krueger, M. W. (1993). Environmental technology: Making the real world virtual. *Communications of the ACM*, 36(7), 36–37.

- Kurtenbach, G., & Buxton, W. (1993). The limits of expert performance using hierarchic marking menus, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.
- Kurtenbach, G., Fitzmaurice, G., Baudel, T., & Buxton, B. (1997). The design and evaluation of a GUI paradigm based on two-hands, tablets and transparency, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.
- Lau, F. (1999). Toward a framework for action research in information systems studies. *Information Technology & People*, 12(2), 148–176.
- Laurel, B. (1993). *Computers as theatre*. New York: Addison-Wesley.
- Mamykina, L., Mynatt, E., & Terry, M. A. (2001). Time aura: Interfaces for pacing. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: ACM.
- Matthews, T., Dey, A. K., Mankoff, J., Carter, S., & Rattenbury, T. (2004). A toolkit for managing user attention in peripheral displays, *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology*. New York: ACM.
- Pine, J. B., & Gilmore, J. H. (1999). *The experience economy—Work is theatre and every business a stage*. Boston, MA: Harvard Business School Press.
- Redström, J., Skog, T., & Hallnäs, L. (2000). Informative art: Using amplified artworks as information displays. *Proceedings of DARE 2000 on Designing Augmented Reality Environments*. New York: ACM.
- Todd, J. T. (1998). Theoretical and biological limitations on the visual perception of three-dimensional structure from motion. In T. Watanabe (Ed.), *High-level motion processing computational, neurophysiological and psychophysical perspectives* (pp. 359–380). Cambridge MA: MIT Press.
- Todd, J. T. (2004). The visual perception of 3D shape. *Trends in Cognitive Science*, 8, 115–121.
- Tsang, M., Fitzmaurice, G., Kurtenbach, G., Khan, A., & Buxton, B. (2002). Boom Chameleon: Simultaneous capture of 3D viewpoint, voice and gesture annotations on a spatially-aware display. *UIST 2002 Proceedings, ACM Symposium on User Interface Software & Technology*. New York: ACM.