# Computer Aided Design: Back to the Drawing Board

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**Abstract**

This paper argues that the role of Computer Aided Design (CAD) should be to enhance and extend paper-based working, rather than to replace it. Current CAD tools are little used in the early stages of designing. Paper is heavily used, with its physical properties supporting work practices that are not possible with CAD. This paper presents implications for the design of new computer-based tools drawn from observations of designers' work practices. A new system is described that integrates paper-based and computer-based working in the same physical space and supports the application of computation to images on paper.

**Keywords**: computer aided design, sketching, user interface, large-area display, observational study.

## Introduction

> An architect is sketching at her drawing board. As she works she glances at her previous sketches that are spread around the board. She reaches for another sketch and overlays it on her work, intently moving her pencil through the air over the paper as she figures out how the roof will work. Without raising her eyes she reaches for her set square, places it and firmly rules a line to mark the eaves. After working a while longer she stands back to look at what she has done, and then wanders round the office looking at other drawings pinned to the walls.

Visually oriented designers, such as the one portrayed above, usually work in a very rich environment, surrounded by examples of work and with a wide variety of tools and materials to hand. Computers are little used in such environments, especially at the early, most creative stages of designing (Hyde, 1989; Tovey, 1989). Paper and pencil is still the medium of choice in many design professions as this best supports the sketching that is so characteristic of these early stages. The vagueness and ambiguity of sketches seems to play an essential part in the creative process, allowing exploration and reinterpretation of tentative ideas (Ballay, 1987; Schön & Wiggins, 1992). For example, Hewson (1990) observes that a pencil is capable of a wide variety of marks and can be used to express ideas at many different levels of abstraction. In addition, the feel of a pencil on paper plays an important role in the making of these marks. Currently available CAD systems are very limited in their mark-making abilities and lack this tactile dimension. They also tend to require highly structured information, making it hard to explore tentative or incomplete ideas.

These difficulties with computer use in the early design stages suggests a range of responses, from complete rejection of computers through to extensive simulation of traditional media on the computer. At EuroPARC we have adopted an intermediate approach that retains traditional media but enhances them with computational tools. We hope in this way to provide an environment for the designer that supports creative work better than either traditional media or the computer alone. The Digital Drawing Board demonstrates one way in which this might be done. It allows the designer to continue working with traditional media, to apply computation to images on paper and to access the computer from the drawing board. The computer display is projected onto a digitising drawing board, allowing the user to interact with the projected image with a stylus. A video camera is used to pick up images from paper placed on the drawing board. Our own studies have shown how a designer at the drawing board makes use of peripheral vision and the kinesthetic sense (sense of bodily position in space) in managing the work. The computer interface has been designed to allow the designer to draw on these same senses in managing the computational work space.

In this paper we first present a case study that illustrates the role of peripheral vision and the kinesthetic sense in design work. This shows some of the ways in which current CAD systems fall short of what is needed to support creative work. We then describe some technological approaches from outside conventional CAD that have the potential to address some of its limitations. These approaches form the background for the design and implementation of the Digital Drawing Board.

## Working at the Drawing Board

It is now widely accepted that to successfully integrate traditional media and computation in ways that enhance creativity we need to understand designers' existing work practices (Hewson, 1990; Suchman, 1987; Tang, 1989). We have observed designers at work in a number of settings in order to develop this understanding. Our most detailed observations have been carried out in two architectural practices but they are backed up by observations of students of other design professions in three different design schools. In this paper we illustrate our findings by using a detailed case study of an architect sketching during the early stages of designing a large domestic house.

The session of sketching arose naturally during the course of observations and was recorded on video. This video was analysed with a view to informing system design rather than scientific investigation (Tatar, 1989). Many interesting features of this activity have emerged but here we have focussed on observations of the use of the work space of the drawing board as these relate directly to the design of the prototype Digital Drawing Board.

### *Work Space Organisation*

The architect was working in an open-plan office with two other architects. His workspace consisted of a drawing board with filing cabinets and shelves to either side. During this session he was working at the drawing board, using pencil on translucent paper. He maintained a recognisable pattern in the way he organised this workspace, although as the session proceeded many of the objects in this space were moved around. This layout kept the relevant objects to hand and kept things currently not needed out of the way but accessible.

The main areas on his drawing board were the central space in front of him where he was drawing, a space to his left where he piled various sketches he had been working on earlier, a space above where he taped currently relevant material and a space below and to the right where he left his tools such as set square, scale and eraser. The parallel ruler across his board, as well as being used for drawing, served as a ledge that stopped the loose paper and tools from sliding off the board (see Fig 1).

As he worked he constantly reorganised this space as different material became relevant.

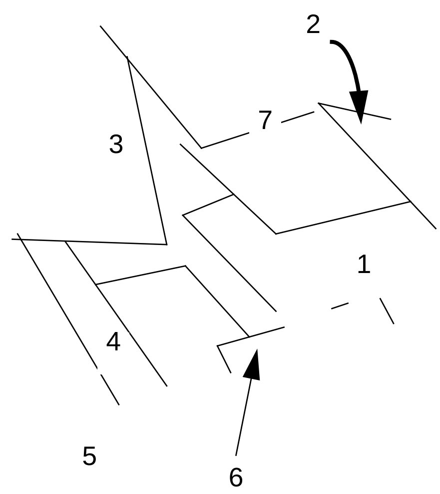


Figure 1. The architect’s working space
1: working sheet, 2: set square, 3: printed brief, 4: pile of sketches, 5: parallel ruler, 6: measuring scale, 7: drawings taped above working sheet

Before starting a new sketch he usually taped some previous drawing to his central area, for example, an earlier version of the same thing or a related part of the house such as another floor. He would then place a blank sheet of paper over the top and start drawing. From time to time he retrieved other related sketches from the pile to his left and taped them above his central work area. As he worked he often referred to these, either simply glancing up at them or else placing his hands or scale on them as he looked. At other times he overlaid further sketches over his work, for example a section over a plan to resolve some issue that could not be dealt with by either the plan or section alone.

When he was finished with a sketch he would place it aside in the pile to the left. Sometimes he placed it carefully on the pile; at other times he simply pushed the sketch aside as he continued working and it would slide down to rest on the parallel ruler. He would turn to this pile and flick through it when he wanted to find some previous sketch that was not visible. Sometimes he kept his fingers on a sketch that had been pushed aside and he could then retrieve it by simply sliding it back again with his fingers.

His tools were habitually left in the same place below or to the right of his working area. Sometimes the smaller tools such as the scale or eraser where held temporarily in his left hand as he continued with something else in his right (he was right handed). These habits meant that he did not need to raise his eyes from the work in order to bring a new tool into use. For example, he was repeatedly seen to reach out for the set square with his right hand, slide it into position along the ruler, hold it still with the left hand and then rule a line with the pencil in his right. When finished he pushed it aside again with his right hand. This pattern of actions happened very fast and appeared frequently in the flow of his drawing activities. He seldom lifted his eyes from what he was doing in order to reach for the set square and there seemed to be no disruption to the flow of activity. One exception was when the set square was not in its usual place, confirming that this habitual placement usually enabled him to proceed with minimal disruption. The other tools could similarly be retrieved without looking.

*Requirements for a Computer-augmented Workspace*

This use of the drawing board draws on a range of different kinds of skills and is heavily dependant on the physical properties of the environment. Hewson (1990) describes in some detail the properties of pencil and paper and the manual skills of using these materials. Here our observations focus on features of the wider environment of the drawing board that allow for the fluid exercise of these skills and play a part in supporting the creativity of designers.

The drawing board provides much more than a space for drawing. It provides views of related materials, as well as easy access to previous work. Peripheral vision and the kinesthetic sense are vitally important in enabling the architect to retrieve tools and materials without disruption of the activity in hand. Items spread out in the space around the main work area can be kept in awareness by peripheral vision and can be referred to by simply raising the eyes. The common habit of hanging relevant material around the walls also shows the importance of material in the periphery. Much of the time it remains in the background but it is very easy to refer directly to a particular piece when necessary. The kinesthetic sense comes into play when the architect reaches for items without raising his eyes from the work in hand. The habitual placing of the various tools allows him to reach out to the expected place, with his kinesthetic sense guiding him. These working practices enable him to focus on the ideas he is developing, rather than being distracted by the means of capturing or expressing them.

Current computer systems do not allow users to make good use of peripheral vision and their kinesthetic sense. With windowing systems it is possible to arrange for several items to be visible, but the space available is usually very limited. Even with large screens the electronic images are in a space which is physically separate from paper, reducing the ability to mix paper and electronic media in a single, uninterrupted stream of work. We should make it possible to place computational images freely in the same working space as paper images and to retrieve them by reaching for them. The mouse and other relative positioning devices make it hard to rely on any absolute sense of space or position. To draw on the kinesthetic sense users should be able to make the same movement every time they reach for a particular place.

The habits of placing tools in particular places or holding tools in the hands mean that the eyes need not be raised from the work in order to bring a new tool into use. Tools for use in the computational environment should be similarly to hand. One approach could be to provide a number of physical input devices, each associated with a different function in the computational environment. Computational functions would be initiated by reaching for a specific physical device. This draws more directly on the kinesthetic sense than, say, searching through a menu with a mouse.

## Electronically-enhanced Design Environments

Conventional CAD tools provide little of the kinds of features we outline above but other work on tools for designers has shown some different and fruitful approaches that come closer. The driving force behind much of this work has been the desire to enable designers who are not physically co-located to work together. The normal physical environment does not allow this as there is no way to see what a person elsewhere is doing, or to work with them on the same drawings. Hence there is a requirement for some form of electronic intervention.

VideoDraw (Tang & Minneman, 1990) enabled remote designers to work together by providing each with a video monitor showing the view seen by a camera pointing at the monitor at the remote site. Each designer could draw on the surface of their monitor with marking pens. In this way they could see what their collaborator was drawing, and could draw over their collaborator's drawing by marking on the surface of their own monitor. The cameras picked up images of the designers hands as well as their drawings, enhancing the interaction by enabling the designers to gesture at the drawings.

TeamWorkstation (Ishii & Miyake, 1991) took this idea further by combining video images with computer images. Remote collaborators could combine marks made on paper, viewed by the video camera, with marks generated on the computer screen. This enhanced the physical environment both by allowing remote collaboration and also by allowing some combining of computational and traditional methods. One limitation was that there was no way to transfer images from paper into the computational environment to apply computation directly to these images. In addition, interaction happened in a space separate from the composite images.

The physical work space provided by both VideoDraw and TeamWorkstation is very small and this is a major limitation for designers, who usually work on large drawing boards. The researchers who developed VideoDraw tackled this by developing VideoWhiteBoard (Tang & Minneman, 1991), a whiteboard-sized work surface that could be shared with the remote collaborator. Each user drew on a ground glass screen, with a camera behind the screen picking up the drawings on the screen and also the shadow of the person doing the drawing. This image was then projected from behind onto the screen of the partner so that they saw their partner's drawings and shadow combined with their own drawings. The ROCOCO workstation, which provides a shared computational drawing surface on a conventional workstation, has also been used to provide a large work surface, in this case by projecting the computer screen onto a large digitiser (Scrivener et al, 1992).

The most direct precursor of the Digital Drawing Board presented in this paper is the DigitalDesk (Wellner, 1991), developed at EuroPARC. It merges the physical and electronic desktops into one and allows the user to interact in familiar, physical ways with both worlds. It consists of an ordinary desk, above which are mounted video cameras and a computer-driven projector. The cameras are connected to image processing facilities that enable the computer to track the movement of hands or other objects so that these can be used for interaction with the computer. The cameras can also be used for reading text from paper documents on the desk, allowing computation to be applied to information in these documents. Electronic documents are projected down onto the desk, as is feedback from the user's interactions with the system. The same physical space is used for both input to and output from the system, and this space contains both physical and electronic objects.

These kinds of systems are often referred to now as "Augmented" or "Computerised Reality", in order to distinguish them from "Virtual Reality". The emphasis is on extending and augmenting the physical world rather than replacing it with a completely synthetic one. People can retain and build on their existing ways of acting in the physical world but can also access new kinds of computational facilities. A perhaps more familiar example that might be considered as Augmented Reality comes from the world of musical instruments, where computerised keyboards, guitars or drums retain the familiar physical interface but provide enhanced electronic features.

## The Digital Drawing Board

The Digital Drawing Board applies the ideas of the DigitalDesk to a designer's working environment. It provides a large drawing board as a work space within which the designer can work with both paper and computational images. The large size of the work space supports peripheral awareness of items placed around it. Computation can be applied to images created on paper as well as those created within the computer, helping to integrate the two media. The kinesthetic sense is supported by using a digitising stylus that operates on the same surface as the computational and paper images and so maintains the sense of physical space in interactions with the computational environment. It has been left for a future project to explore the use of multiple physical input devices.

The current prototype (Fig. 2) makes use of a computer display projected onto an A1 (841mm x 594mm) drawing board that can be used both in the traditional manner and as a digitiser. The projector is driven by a VGA card, mounted in a SPARC II workstation, which displays 640 x 480 pixels (giving about 8 pixels per cm). The DigitalDesk toolkit developed at Rank Xerox EuroPARC (Wellner, 1993b) calibrates the coordinate space of the digitiser to that of the projected display.

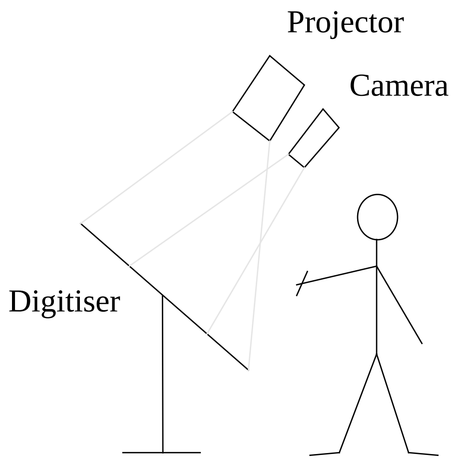


Figure 2. The Digital Drawing Board

The organising computational object is a “sheet”, a graphical object contained within a rectangular frame. These sheets can be positioned freely within the space available, stacked or spread out. In order to give a strong kinesthetic experience of the computational objects, sheets are organised by applying gestures directly to them. For example, tapping on a sheet and then dragging it moves it to a new position; flicking downwards on a sheet flips it behind any sheets it is resting on. Gesture recognition is triggered by a distinguishable stream of input events, currently those produced when the side switch of the tablet stylus is depressed. Other input events go directly to the application behind a particular sheet. Recognition is carried out by specially written software that distinguishes a small range of single-stroke gestures: lines in various directions and caret shapes in different orientations.

A camera mounted alongside the projector supports the transfer of images from paper into the computational environment. The camera settings are controllable from the computer so that the user can easily set up the image to be transferred. A VideoPix board is used for digitising the image. The Digital Desk toolkit provides adaptive thresholding and scaling functions for processing these images (Wellner, 1993a). The field of view of the camera can also be calibrated to the coordinate space of the projected display using other toolkit functions (Wellner, 1993b). This supports the interactive selection of regions for digitising.

*Prototype Application*

Many activities which could be helped by computational support go on during the early stages of graphically-oriented design. One example from architecture is visualising the appearance of a building from sketches and plans. This can be particularly difficult for the clients, who probably lack any specialist experience. Similar visualisation activities also occur in other design professions. A small sub-part of this activity has been selected for the prototype application, which provides an interface for digitising sketches on paper and for rendering images using standard software (Renderman). The digitised images are used as texture maps for rendering the surfaces of solids of revolution. This could in future be extended to the rendering of more complex models.

*Preliminary Observations*

A number of different designers have used the prototype application, although we have not formally tested it. An immediate reaction is that the projected image on the drawing board is easier on the eyes and easier to relate to than the much more constrained image on the workstation. It has a familiarity that the workstation lacks. Several designers have said they like the way they can stand while they work with the Digital Drawing Board, rather than being obliged to sit down. The size of the space available is seen as much less constraining than a conventional workstation, but without more realistic and extensive use it is not possible for us to say if we have successfully supported the use of peripheral vision and the kinesthetic sense.

The large projected image is publicly available in a way that conventional computer screens are not. It is very easy for a group of people to stand around the Digital Drawing Board and discuss the images being displayed. In a design studio someone passing by might stop to comment on work in progress at a drawing board. Current CAD systems make this much harder as very little can be seen. In a studio using the Digital Drawing Board the computer-based work would be as publicly available as the work on paper, thus supporting the collaborative nature of designing.

An unexpected effect is that paper placed on the Digital Drawing Board tends to be seen as transparent, as the images on the paper combine with the images being projected. This combining of images is specific to a front-projection system and is a feature to be explored further. Under some circumstances this could be experienced as annoying interference, but on the other hand the observations of paper-based work showed extensive use of translucent paper for combining images. This suggests that the translucent and transparent effects achieved on the Digital Drawing Board could be put to good use in combining computational and paper images.

The main drawback with the current prototype is the shadows cast by people standing in front of the board. This is particularly noticeable when someone leans forward to look closely at something. The DigitalDesk did not have this problem as projection was from directly overhead onto a horizontal surface and so the user's body was not in the way. Because the drawing board is mounted at an angle the user is much more likely to obscure the beam from the projector. This could be overcome by using a curved mirror to allow projection onto the sloping board from directly above.

## Conclusions

Our observations of designers at work have illustrated the role of the physical work space in supporting their practices. A large and flexible space is very important to many designers, and the use of this space is tied very closely to the way that paper can be handled and spread around. They make use of peripheral vision and their kinesthetic sense to maintain awareness of related work and tools. Current CAD systems lack this physicality and presence in space and do not draw on such a wide range of skills. Other approaches that make use of video and projection systems demonstrate a way of giving computational systems a greater physical presence. The Digital Drawing Board does this by providing a large work space in which projected computational images can be placed. Paper images can be present in the same environment and computation applied to digitised video images of them, allowing closer contact between physical and computational worlds. In this environment paper and computational media can be complementary, with each being used for the tasks for which it is best suited. CAD is no longer seen as a replacement for paper but rather is available alongside it to enhance and extend traditional methods of working at the drawing board.

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