*i*NAVIGATOR: A SPATIALLY-AWARE TANGIBLE INTERFACE FOR INTERACTIVE 3D VISUALIZATION

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Abstract. The purpose of this work is to design a spatially-aware tangible interface for interactive 3D visualization. We explore an integrated platform whereby digital representations are integrated with physical artifacts. Our work provides a means to display separated perspective views of a design on multiple-projection physical planes. Users can directly interact with the physical planes to view digital information. By coupling physical artifacts with digital representations, the view of 3D information is mapped to physical space. Our work reduces the cognitive load on novice designers, and enhances the user's capability of understanding the relationships between multiple design representations.

1. Introduction

Architecture has relied upon multiple representations to depict building designs, inspect details, and share ideas with collaborators. Design representations range from floor plans, elevations, sections, to detailed 3D massing models. By integrating these multiple "views" of a design, designers build a cognitive model in mental construct. Developing skills to integrate and articulate multiple design representations has become a fundamental component of architectural design education.

Today, CAD systems allow designers to construct 3D geometric models through a set of operations. Interacting with digital information has largely relied on mouse, keyboards, and computer screens. In a desktop setting, multiple views of a design are displayed independently on a single computer screen. Understanding the spatial relationships between multiple views is still a "hidden" work without computer augmentation. Moreover, physical and digital representations are divergent, resulting additional cognitive load on designers. There is a growing concern with how to integrate divergent media for use in design. Architectural CAD has not yet changed this fundamental condition in interface design.

This recognition suggests the need of an integrated CAD platform for articulating multiple physical and digital representations to reduce the cognitive load on designers. The platform should retain the desirable simplicity, allowing designers to transfer their considerable skills they have acquired from working with traditional media. We hypothesize that tangible interaction can afford an intuitive way of working with combinatorial design media.

In this paper, we present a tangible user interface for interactive 3D visualization. We use "cutting plane in hand" as an interface metaphor to design the tangible media. Design representations are displayed on multiple-projection physical planes. User can directly manipulate digital information associated with the corresponding physical planes. By coupling physical artifacts with digital representations, we can enhance the user's capability of understanding the relationships between multiple design representations. The objective of this paper is to develop an integrated CAD platform that is mapped to physical space, whereby we can potentially take the cognitive load off the designers.

2. Related Work

There are a number of efforts to integrate physical and digital representations. Most of these are now being based on the tangible user interface concepts [Ishii and Ullmer, 1997]. Many methods for extending computerized workspace beyond the computer screen have been developed, turning real-world surfaces into interactive surface [Rekimoto, 1997] [Rekimoto & Saitoh, 1999]. Our work is inspired by the development of the augmented desk system whereby a real desktop is transformed into a computer screen [Wellner, 1993]. Our work has similarities with those developed by Piper et al. [Piper, Ratti, and Ishii, 2002]. Unlike Piper et al., our work provides the user with the ability to directly interact with the physical artifacts to view digital information. Our tangible system allows interactive 3D visualization with a realistic amount of details, and without an excessive amount of manipulation.

3. Design Conception

Design can be considered as a cognitive process that transforms external design representations into designer's conceptual world through multiple sensory modalities [Eastman, 2001]. Multiple modalities depend on how we create a user-friendly interface in such a way that external representations can be intuitively mapped to internal representations. In order to understand how user interfaces affect the design process, we conduct an empirical study by observing several design studios in architectural school. We observed and analyzed how the designers acquire their considerable skills from working with tradition media. The idea is to recapture the design conception and interaction properties of conventional design interfaces that were lost in the computer revolution, rather than moving back to traditional media.

Our studies showed that tabletops and walls are the primary media used for organizing external design representations. Designers often use tables as a large horizontal surface to create and share a design. They draw their ideas on sheets of paper and address some issues on the table surface. In the mean while, they pinup their drawings, photos, and sketches on a wall for design reviews and critiques. Walls have been served as a vertical surface for information sharing. In comparison with a small computer screen, spatial elements (e.g. tables and walls) afford a large-format display that is easy to view, make annotations, organize and share ideas. The interface is depicted in Figure 1.

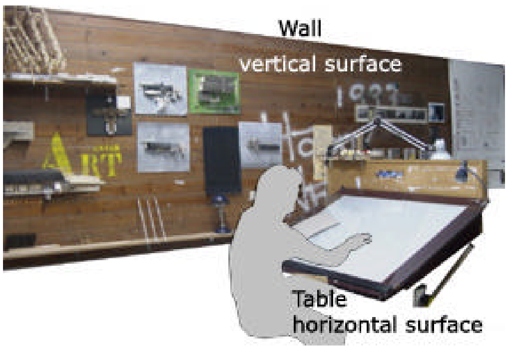

Figure 1. Tables and walls serve as a large-format interface for information sharing.

Apart from the affordance of spatial interfaces, the idiosyncratic technique that designers often use is coupling floor plans and sections together as an integral whole, as shown in Figure 2. Our observations conclude that by coupling building sections with floor plans, users can easily conceptualize an integral 3D model in mental construct. By virtue of its horizontal and vertical settings, the users can construct topological relations of connectivity in a cognitive space. We hypothesize that by mapping digital representations to physical artifacts (e.g. tabletops and walls), we can preserve the affordance of traditional media.

Figure 2. The designer organizes information by coupling a physical section model with the floor plan in a spatial setting.

4. Designing for Interaction

Our work is inspired by our previous empirical studies on the traditional architect's design studios where designers organize their drawings on tabletops and walls in order to share, present, and critique a design. Our idea about a CAD platform is straightforward. That is, we propose a tangible user interface for CAD drawings using a physical plane to visualize the cuts and sections views of the 3D model, as shown in Figure 3.

The first prototype implementation comes from our earlier studies of the "interactive table (*iTable*)", which is essentially an office table with a computer image projected from the overhead onto the surface [Jeng et al., 2002][Jeng and Lee, 2003]. Designers work on the surface using an interactive whiteboard device, much like they would work with paper on a traditional drafting table. It is a user interface demonstrating new interaction technique what is called "tangible User Interfaces"[Ishii and Ullmer, 1997], employing physical objects, instruments, surfaces and spaces as physical interfaces to digital information. By contrasting with the formal operations in desktop computers, it is easier to manipulate and organize.

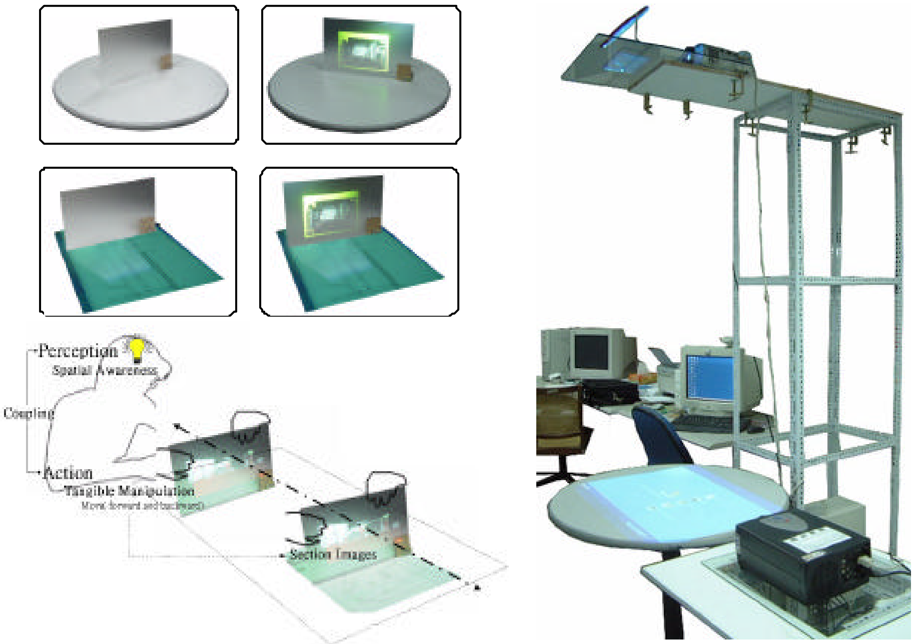

Figure 3. The setup of the interactive table

5. A Tangible Interface for Spatially-Aware 3D Navigation

We set up an interactive table by installing an overhead projector with mirror, which refracts the building plan geometry onto a table surface. Likewise, a section view of the building is projected on a spatially-aware display tablet that serves as a cutting plane over the table surface. Moving the tablet will trigger the display of related section views corresponding to its location to the building plan geometry. More importantly, users can move the display tablet freely and acquire a sequence of section images displays, resulting in a “live” walk-through animation, as shown in Figure 3.

The position of the display tablet is sensed based on camera-based color recognition of LED infrared light embedded in the tablet, illustrated in Figure 4. Users can perceive the 3D model while they move the tablet forward and backward.

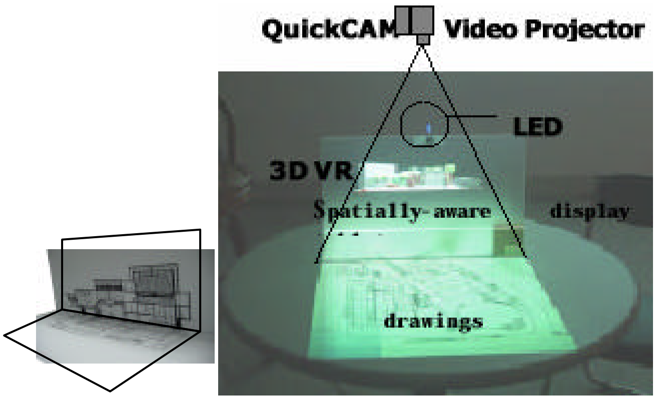

Figure 4. A semi-transparent tablet can be dynamically placed on the plan drawing to display spatially-contiguous section images of a 3D digital model.

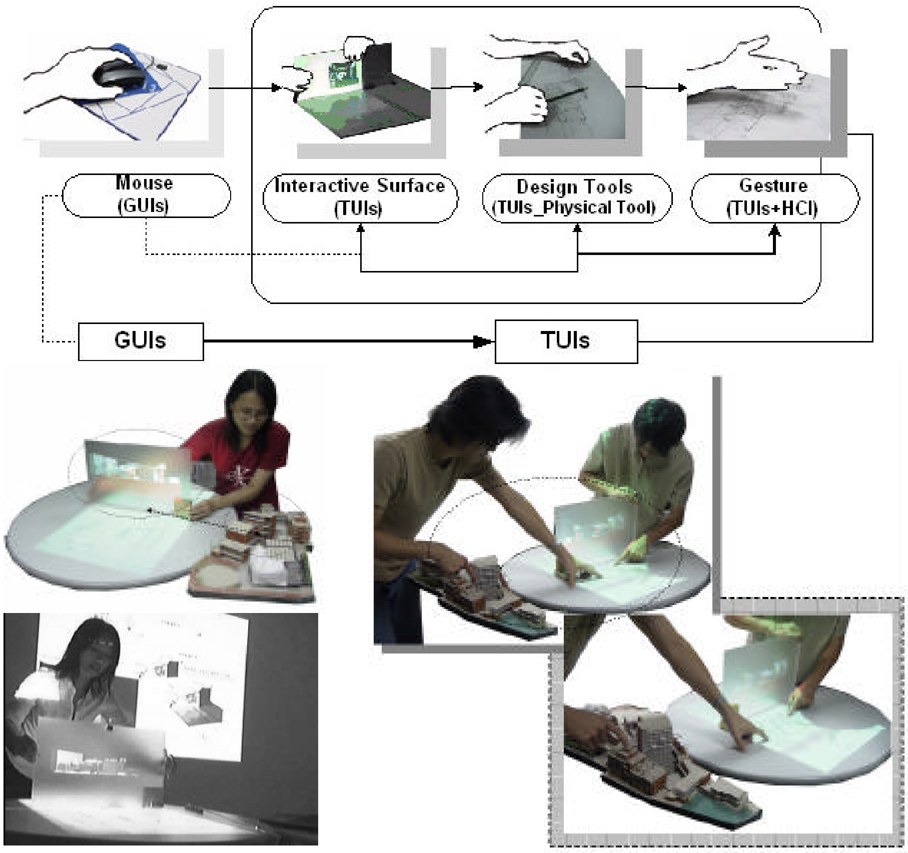

Figure 5: By virtue of "cutting plane in hand" interface metaphor, the users control the physical glass planes to visualize different slices of brain images.

Besides, that digital information mostly accompanies traditional medium (e.g. physical model) for more clear explanation. The participants' focus always switches dynamically and the information we gathered is always broken into pieces. It is necessary to integrate multiple representations synchronism and couple action and perception seamlessly so that the participant can switch their focus smoothly and get a clearer picture of the relationship among the data. Our "cutting plane in hand" metaphor couple with table surface for interaction has been related individual work to the group as a whole. Hence, we have built a tool, the interactive tablet, served as "a cutting plane", which is corresponding to the position of the tablet with reference to the building plan geometry on the table surface. The objection of this work can be described as follows:

- automatic retrieval and dynamic representation of relative information;
- intuitive manipulation and movement for acquiring useful information.

The system acts as an integrated shared *information space* among participants simultaneously. The large size of the projected surface supports share awareness, the social and collaborative properties of the traditional studios that were lost during the computerization. Collaboration is aided by coupling action and perception in tangible manipulation, which supports synchronous, asynchronous communication capabilities and spatial awareness of the project.

6. *iNavigator* Prototype Implementation

In order to put this research work into practice, we start to implement a new CAD platform called *iNavigator*. We install our innovative tangible interface systems in our Information Architecture lab, as shown in Figure 6, the new prototype consists of horizontal and vertical projected planes as physically interactive surfaces. Horizontal plane is an overhead or rare projection table with semi-transparent glasses covered on which we project the plan drawings of the 3D CAD model. We also design a portable frame which mounts a rotative mirror on the top. There are two slabs on the side for placing two projectors. We can adjust the height of the slab flexible to fit the projecting image to the right place. Other fixed components in physical space include interactive whiteboards (e.g. mimio) and web cameras.

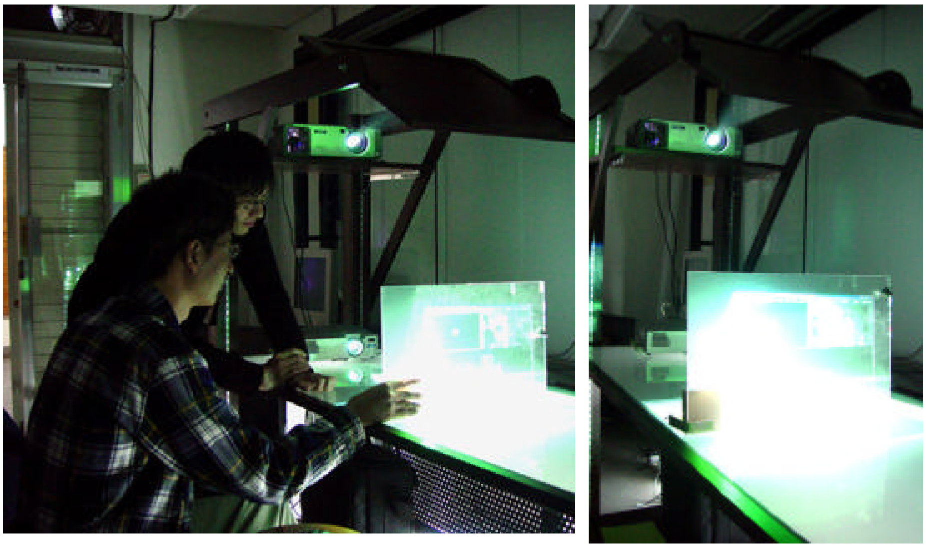

Figure 6: The new version of the spatially-aware 3D interactive device for empirical studies

The vertical plane is a tablet consisting of a semi-transparent glass and a Light-Emitting Diode (LED) embedded. The mounted LED is capable for vertical moving to determine the positions of vertical sections. Users can manipulate the positions of the LED on the tablet vertically or moving tablet on the table horizontally. CCD Cameras and Image processing techniques are deployed for recognizing the position of LED and displaying horizontal and vertical sections of the 3D model. The perspective viewpoint of the 3D model is projected on the wall-sized screen that allows designer to execute view command via LED-mounted tokens.

Tokens are physical objects augmented with digital capabilities for representing execution commands. The LED-mounted tokens are used for view commands, such as Section. As shown in Figure 7, Image processing techniques are used to recognize the colors and positions of the tokens. LED-mounted tokens captured from a CCD camera under the semi-transparent glasses (figure7-right). The problems we encountered here are about the unstable qualities of recognition results generally caused by the environments and the accuracy of executing recognized commands.

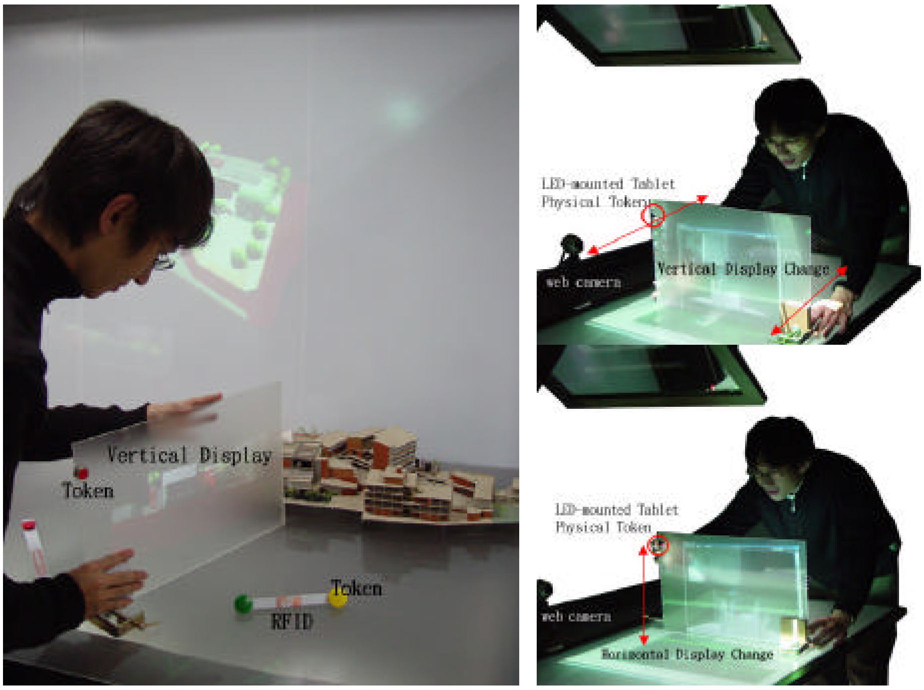

Figure 7. The prototype consists of horizontal display and vertical display for representing 3D geometry interactively through placing LED-mounted tablet and manipulating physical tokens.

Our observations showed that it is easier for designers to examine the spatial qualities of a design through horizontal and vertical section projections as physical constraints. Physical glass planes are used as interface metaphors. The system is capable of leading the users to comprehend the characteristics of digital 3D spaces. It is essential that designers inspect and modify 3D geometry through graspable objects in an intuitive way. The achievement of the spatially-aware *iNavigator* systems includes:

- Coupling multiple viewpoints (e.g. plans and sections) in an integrated multi-device environment for supporting holistic perception of a design, and
- Coupling actions and perception in manipulating physical tokens in order to construct and modify 3D geometry intuitively.

7. Conclusions

In this paper, we review some of our empirical studies, in a manner supporting conceptualization of interaction design. Our observations conclude that the desktop-based user interface is inadequate to support design conception compared with how we interact with traditional media such as pens, paper, walls, and tables. When interacting with physical artifacts, we use natural skills that we acquire in our everyday lives. We use multiple sensory modalities such as touch, speech, and vision to manipulate physical objects simultaneously. We do not think about how we manipulate physical artifacts because the skills are embedded so deeply into our minds and bodies.

We describe *iNavigator* as a CAD platform that uses tangible user interfaces to visualize and inspect 3D geometry by manipulating physical tokens. We have demonstrated how the spatially-aware tangible interface can afford correlations of multiple representations, encourage share awareness, and enhance spatial cognition in inspecting 3D design information. Design collaboration is aided in part by coupling action and perception in tangible manipulation of the *iNavigator* system. An important goal is to map the view of 3D information to physical space by augmenting physical objects with a wealth of digital information and interaction capabilities.

Coupling actions and perception in digital augmented spatial settings will improve current CAD systems into a direct-interpreted 3D design platform. Our studies show that embodied interaction is possible with respect to the spatial and social factors of design conception. The techniques of embodied interaction go beyond current presentation tools. The *iNavigator* system is a working prototype in the very early stages of development toward embodied interaction. We have also highlighted some of the drawbacks of inaccuracy in vision recognition for manipulating 3D geometry in real time. Some technical and social issues will be resolved in future work.

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