

Transformable Physical Design Media

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Computer-aided design tools have become an integral part of much architectural design practice, to the point where design is heavily dependent on the assistance of these tools. But current computer-aided design tools are fundamentally limited by the WIMP (windows, icons, menus, and pointer) interface, reliant on 2d input and output. Design of buildings and other 3D objects via 2D workflow is slowed by the conversions that designers must make. In this paper, we explore the potential of transformable physical design media through two design tool prototypes: Integrated spatial gesture-based direct 3D modeling and display system (InSpire), and tangible objects based massing study tool kits (CuBe). Both of these design tool prototypes allow designers to develop their design within a fully 3d environment with optical and haptic references, so that the interaction between designer and design object become much more intuitive and direct. We conclude by discussing some related subjects in the domain of HCI and argue that transformable physical design media represent a desirable solution for enhancing design experience. Architects and designers could benefit from the usage of transformable physical design media, especially during the early phases of architectural design by allowing designers to efficiently alter the topology properties.

Keywords: *Human-Computer Interaction, Design Media, Hand Gesture Input, Augment Representation.*

INTRODUCTION

The nature of architectural design is that of materialization, reflecting the designer's creative thinking. WIMP-based computer-aided design tools have been redefining the foundation of architectural design. While architecture focuses on materialization of design architectural designers work increasingly through the medium of computer-aided design, and while both 2D drawings and 3D models may be cre-

ated and manipulated, the underlying mode of interaction remains predominantly 2D, created through keyboard, mouse and monitor. It is not capable of fully representing physical 3D objects. We believe that the interaction between designer and design objects through these tools needs to be enhanced and we are seeking a brand new design medium which can provide a more direct and intuitive interaction to help designer inspire and improve their de-

sign intent.

This is necessary because the tools selected by architects have significant impacts on design objects, and on designers' thought processes. Many architects are spending considerable time learning to use software and solving software problems that are not design problems. The manipulation of the user interface, interacting through data, keeps confusing professional architects, leading to reduced efficiency and misunderstanding of projects. Architects, who used to work with descriptive drawings and physical models, have become monotonous computer operators. Architectural design, which is supposed to be an interesting and creative process, can become a repetitive electronic task, while knowledge and skill accumulated through design education and long term professional practice are now replaced by computers.

A brand new Computer-Aided Architectural Design system needs to be created which can inspire designers by deemphasizing computer manipulation.

BACKGROUND

Aleksander (1999) and Kalay (2004) identify three generations and two tracks in the development of CAD tools (Figure 1). The two tracks are distinguished by the purpose of development: an engineering-oriented track (CAD), in which development, was often led by industry heavyweights such as General Motors, and an architecture-track (CAAD) which was usually led by university-based research.

The first generation of CAAD systems were designed to be intuitive and architectural. But the shortcoming of 1st generation of CAAD was that it tried to contain the entire architectural design process, and failed. The engineering-track CAD system, based on 2D wire-frame modeling, was already being applied in engineering practice while architectural CAD was still in gestation. With the growing demand of automotive and aerospace industry in 1960s, engineers sought new ways to define complex geometry. Before long CAD technology broke through from 2D wireframe modeling to 3D modeling, and complete assemblies could be defined in CADAM systems.

In 1980s, during the PC revolution, the second generation of CAAD system focused on drafting and modeling, defining the different types of geometries rather than defining the building element properties. They all focused on 2D and 3D geometry such as line, poly-line, surface and simple geometric relations. Meanwhile, engineers developed solid modeling technology which can illustrate the topological relationships as well as the geometric physical properties.

The third generation of CAAD system had become far more complex than the previous, architectural elements are interdependent, and the number of these elements is large. The third generation of CAAD system (BIM) seeks to manage the large amount of associated data.

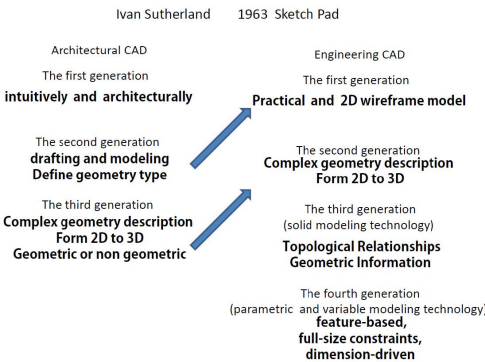


Figure 1
a comparative
history of CAD
development

CHALLENGE

We might conclude that the computer-aided design technology used in Architectural industry is always adopted from engineering track because of the practicality, reliability and stability required in architectural practice. Is it impossible for any form of experimental reforms to firstly happen in architectural industry? Does adoption provide the best fit for architectural designers?

Architectural designers are responsible for designing the aesthetics and spatial details of a building. Design is an act of seeing, thinking, and making.

ing (Lobel, 2009), combining eyes, brain and hands. Through the association of all three, architectural designers are aware of information; through the iterative process of design, architects have the chance to re-define information and get feedback so that they can make the right decisions.

CAAD tools provide us with a new means to explore new ideas, and introduce the designer to new metaphors. But, if architectural designers don't actively and critically consider how the changing technology can impact our ability to communicate and think, that CAD technology could equally well be crippling.

THE TRANSFORMABLE PHYSICAL DESIGN MEDIA

The tools which architects need should be designed to offer more freedom, expanding their design capabilities and enhancing the communication of design process. These tools should be able to support the architectural designer to effectively deal with more creative issues and complete their work with fewer restrictions. We believe such a system needs be developed in two different ways: through efficient tools and through revolutionary paradigm-shifting tools, but that these will be eventually integrated together into a new platform. This paper describes a paradigm shift.

The classic 2D GUI, produces huge numbers of design drawings. But the experience given by the physical presence of architecture is significantly different from the designers' experience given by design drawings. Our vision for future design activity relies on developing a brand new design media integrating intuitive tools and augmented representations to enhance the design experience. Media is more than just a "tool", as articulated by McCullough (1996), media is also an environment where in our minds and bodies fully take on the issues of design. Tools, incorporating intuitive input via physical manipulation will be mastered quickly by designers. Immersive augmented displays will enhance the physical interaction with designer with information fo-

cused on the design object, not the interface. As a result the designer's experience of the object during design will more closely approximate the informed physical experience.

But if we are talking about the tangible media in design space, one of the fundamental challenges is that design process are always dynamic; design objects keep changing. Generally, when people interact with a physical object, they do so through theoretical abstractions or physical entities (Ceolho 2009). The surfaces of the object are boundaries through which we interact with things. Surface will eventually define physical forms and the form can be sensed by human. Thus, a transformable surface will impact the designer's cognition. In mathematics, surface changes are usually realized by topology transformation. But in the physical world, transformations are limited to additive or subtraction processes. Based on the shape-changing study, currently available transformation of object potentially could be realized through topological transformations and textural transformations.

We are seeking a design-oriented manipulation concept which avoids indirect input manipulation and provides more direct relations to the object. This concept can be illustrated in the context of driving a car. Manipulating the steering wheel and pedals, the car responds immediately to the driver's actions, and these responses are immediately evident. If the driver turns too sharply, they quickly recognize this and perform a corrective measure. But try "driving" from the back seat of the car, giving a stranger directions. The indirect manipulation provides no feel for the road and the passenger doesn't have a direct view of where he is going.

We need to find better methods for designers to interact with their design, not only through mouse and monitor, but also through more intuitive and natural ways to sense and manipulate the project. The most intuitive tool should incorporate input manipulation through a natural language. Natural language in this context refers not only to a language like English, but also to human behaviors such as

hand gestures. If the manipulation setting can be based on natural behaviors, it will be easy enough to be learned. The circular flow of information among thinking, observing, and making gives designers the opportunity to dynamically re-define the objects they sense. Body manipulation motivates designers evaluating object from multiple aspects so that inspire appropriate design intent. Grandhi (2011) explored people's natural gestures using "before" and "after" pictures and instructing participants to perform the gesture needed to get from before to after. The experiment suggested that user experience could be enhanced by developing the gesture vocabulary based on understanding that the actions are embodied.

Given the importance of visual feedback to designers, visual immersion incorporating both geometric and non-geometric feedback, is desirable but current hardware often interferes with UI interaction or communication. An augmented representation as output display has several approaches to enhance the experience of designers and achieve the desired results.

We report here on two projects that incorporate input using hand gestures and augmented output. One focuses on gesture and visual feedback, the other on haptic interaction and visual abstraction.

RESEARCH PROTOTYPE I, INSPIRE

The first project, InSpire, emphasizes the visual experience during design process by using virtual reality technology. A virtual 3d representation provides designers a co-located and coordinated mix of synthetic and real visual feedback to facilitate design generation. Current technologies such as virtual-reality headset devices and holographic technology can help achieve the idea smoothly. However, while operating these devices via gesture manipulation, precise pointing is an issue because a purely optical representation does not enable haptic feedback. While developing InSpire, we found that unlike 2D mouse input, where the operating surface under the mouse provides extra support in the vertical dimen-

sion, the fully three dimensional gesture manipulation in a virtual-reality environment lacks a stable reference plane.

InSpire combines an optical see-through display and gesture input, enabling users to directly interact with the system using spatial gestures in the same visual volume as the displayed geometry. The actions of input are three dimensional and output display is virtually three-dimensional.

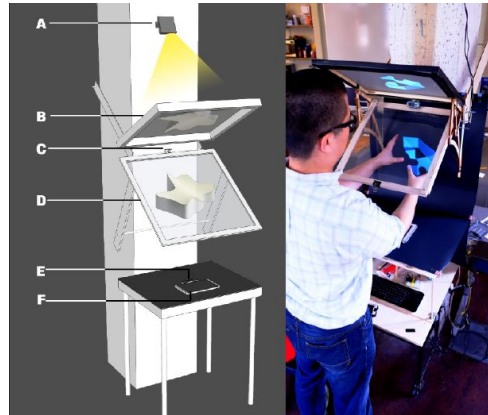


Figure 2
Physical
configuration of
InSpire

The current physical configuration for InSpire is shown in Figure 2. It is a single user installation consisting of a CPU (not shown), a mini projector (A), a rear projection surface (B), an RGB webcam (C), an adjustable semi-reflective plastic surface (D), a Leap Motion sensor (E) and a tablet (F). The virtual geometry is displayed on the semi-reflective surface, which acts as a see-through holographic screen. The size of the display screen and the volume below it roughly match the sensing range of the Leap Motion sensor. This configuration allows a single user to put their hands below the display screen without obscuring content, allowing their hands to directly (if virtually) "touch" the 3D model. The Leap Motion sensor placed on the bottom surface tracks the hand. The tablet placed next to the Leap Motion provides a control panel to switch between different functions. The semi-reflective surface reflects only the light parts of

the projected 2D image; dark areas allow the user to see through to the space below the surface.

Figure 3
Viewing the same Holo-geometry from different angle(b) with head-mounted LEDs.



Figure 4
6. Modeling mode gesture: (From left to right) push, click, drag, select and Triggler mode gesture

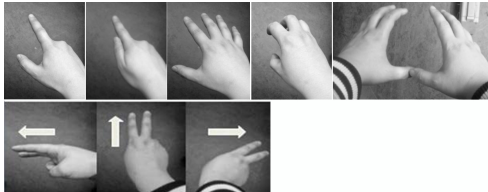
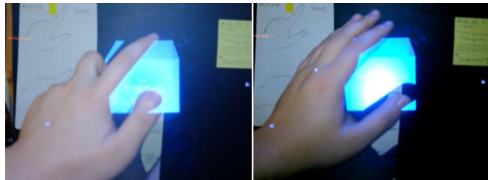


Figure 5
occlusion display



During project development we found that although the mirrored image on the display provided users some sense of depth, the absence of motion-parallax was a problem. To address this, we added a webcam and head-mounted LEDs to provide head-tracking (Figure 3). The user interacts with the mirrored shape in the display. The webcam tracks the user's head position and automatically updates the viewpoint used to produce the model display .

Hand gestures are used to perform geometry manipulation-creation, scaling and rotating geometric elements-while more abstract operations, such as file save, object deletion, and attribute assignment, which lack natural gesture mappings, are carried out on the tablet.

The Leap Motion sensor captures the position, trajectory, and speed of fingertips and palm, producing a compact "hand" data structure which we

transfer into Grasshopper, where we extract the coordinates of the hand. Within Grasshopper, command gestures are identified and acted on. For head-tracking, images from the webcam are processed to isolate the LEDs. Based on the 2D positions and separation between the LEDs we compute a 3D head position, which is used to control Rhino's scene rendering.

The InSpire system uses two types of gesture (Figure 4) : modeling mode gestures and trigger mode gestures. The modeling mode gestures support direct manipulation of geometry in the modeling application - including continuous drawing, scaling, rotating, and selecting. Trigger mode gestures are used in the navigation application-swiping two fingers defines a vector which the system applies as an adjustment to the camera view-vector.

All the gestures are pre-set in the Grasshopper definition, based on features such as the number of fingers & palms and the movement of fingertips. Once a gesture's feature gets confirmed, a command is activated to manipulate the geometry. When a model is complete, the user can use the tablet for saving files, setting layers or deleting objects.

The shape seen on the screen is a 3D projection, reflected from the surface between the user's eyes and hands. Their spatial sense may will be confused if they see the geometry displayed "on top of their hand" even though the geometry is spatially positioned "behind" the hand. In the real world parts of user's hand should block, or occlude, the geometry of the model, depending on the distance of hand and geometry from user's eyes. We address this issue in the way we render the hands. The Leap Motion data stream reports fingertip positions and the palm's center. Using the hand data, InSpire generates a correctly-positioned 3D hand shape in the model and applies a flat black texture to it. Since black areas of the display are not reflective, when any part of the hand is in front of the model geometry, that geometry is partly or completely blocked by the hand's black shape and the user sees through this part of the display to their own actual hand in correct relation to

the 3D model, enhancing their sense of immersion. (Figure 5)

We have used the InSpire platform to develop for two designer-oriented applications. The most mature and important application so far is the modeling function (Figure 6). Using it, a designer can build a 3D model with hand gestures just like sculptor and observe it from many different angles. Modeling mode gestures exist for drawing lines, poly-lines, and curves, as well as creating single or multiple simple and complex surfaces and 3D volumes. After the geometry is created, users can edit an existing object via "hot wire" cutting gestures and control-point "tweaks" to further develop the free-form geometry, as well as moving, scaling and rotating objects. As an architectural design tool, InSpire also allows users to set the geometry of different architectural elements on different layers.

The InSpire system can also be utilized to navigate a model, but space limitations do not permit us to describe it here. Instead, we move to a brief discussion (Figure 7).

One fundamental difficulty is that architects must provide small-scale size and position control of large objects. Although the 3D "holo-interface" enables manipulations with one more dimension than available with a mouse, vision-based positioning is approximate. In the traditional CAD system, object snap features are available to make the modeling job more accurate. Without object snaps InSpire remains useful in massing studies which occur at a very early phase in the entire design process, but is less helpful when working with complex models or detailed geometry. Related to this issue, the interface enables one to directly manipulate the model geometry, but it is difficult to measure the depth dimension accurately. Features such as head tracking and hand-model occlusion partially solve the problem, but another strategy, such as adding a projected outline of hands to both of side and bottom in the display, or voice-activated positioning constraints, might further enhance the experience.

Another fundamental problem is the lack of tac-

tile feedback. In the physical world, when people are manipulating an object, there are at least two senses that help them to feel in control of the object--visual and haptic. The InSpire system is now focusing on the visual interaction. A touch sense could help to enhance the participation of hands. A potential strategy could be wearing tactile feedback gloves. An alternative approach is explored in CuBe (below).

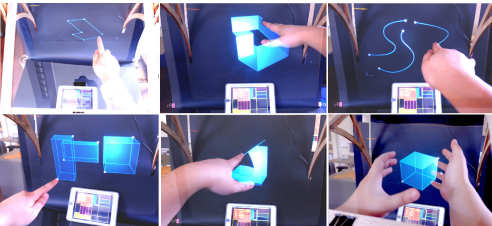


Figure 6
Gesture modeling applications

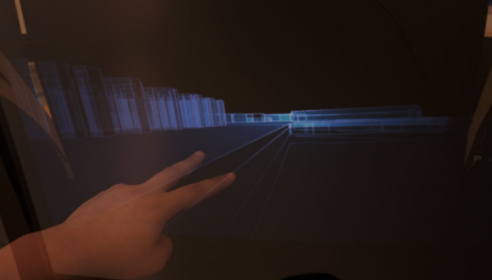


Figure 7
Navigation Function

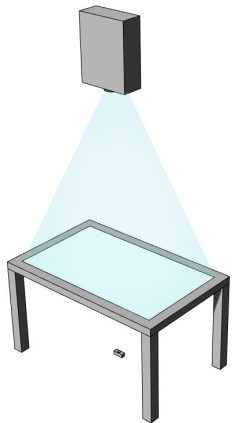


Figure 8
CUBE system configuration

RESEARCH PROTOTYPE II, CUBE

Another prototype CuBe combines transformable representation with gesture manipulation which can give designers a multi-somatosensory cognition. When manipulating objects directly through gestures, designers gain more information than through a purely visual experience. Besides, directly manipulating a physical object, designer can establish a three-dimensional control with more accuracy.

Combining input and output in the same 3d volume seems to be a solution of producing direct and intuitive design media. But during the development of InSpire we had to predefine the gesture vocabulary, drawing from our design experience. The resulting pre-set gesture set will not be "intuitive" for all users. This raised the question of natural gestures or gestures customized by users.

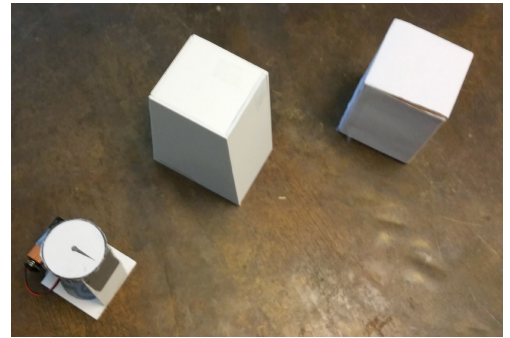
In the physical world when people are manipulate an object, as when picking up a fork,, they don't think about which gesture to use. The gesture come out spontaneously based on current conditions. In the physical world, a physical object will provide people haptic reference in addition to visual experience. Haptic feedback helps judge how much force to use when lifting.

As discussed above, a tangible user interface could be a possibility. Designers could directly work on a physical object to improve their design with more direct and intuitive interaction. Using a physical object to represent building geometry let designers better experience their design object and feel the proportion of the building shapes. To explore this concept, we developed CUBE, a tool kit of tangible objects for performing massing study.

The general environment of CUBE contains a projector, an interactive desktop, and several tangible object tools with augmented reality (AR)-markers (Figure 8 & Figure 9). The interactive desktop is an ordinary desk covered by rear-projection film. It needs to be associated with the projector on the top, and a regular web-cam from below. Software components were built using Processing, UDP, reacTIVision and Grasshopper. ReacTIVision senses the AR-marker

and transfer to Processing then send the data though UDP to Grasshopper.

We developed three tangible object tool kits for massing studies.. The first set is three static geometry shapes: a cube, a keystone, and a tapered (Figure 10). Each object represents a single building object. On the bottom of each shape the AR-marker is tracked by the webcam below the table..



When user places any of the shapes on the desktop, the system responds in various ways. The user can move or rotate the shapes to do the massing study

Figure 9
QR marker used in
CUBE

Figure 10
static geometry,
cube, keystone,
and, tapered

Figure 11
transformable
twisting block

and evaluate what would be the best location and orientation of building. But when you get involved in form finding or more complex composition, the static geometry is not sufficient. So, we developed a set of transformable twisting blocks (Figure 11). For each transformable twisting block there is one potentiometer and one slide potentiometer inside the object. The rotational potentiometer senses the twist angle and a slide potentiometer senses the vertical height change. Both of these potentiometers send real-time data to the display computer, thus the system can apply the data to generate a matched digital model automatically.

The transformable twisting block affords more design tasks, such as evaluating a high raise building shadow situation or curtain wall reflection simulation. But the twisting block only provides two degrees of shape freedom, the rotating angle and the height. What designers need is more flexibility and less limitation. Therefore, we developed the third version of the tangible objects based massing study tool kits.

The third version of CUBE is made up of 10 transformable edges (two of them are diagonal) and 4 fixed edges (Figure 12). Each of transformable edge includes a slide potentiometer which connects to a central micro controller. An AR marker is also necessary for tracking the location and orientation. The designer can consider the CUBE as a proxy for a single room or a building geometry. He or she will just need to lengthen or shorten the transformable edges to change the shape, proportion, and scale of the cube. Based on the sensed edge lengths, the computer utilizes trigonometric functions to reconstruct the shape of CUBE, then the transformations are remapping into a matched digital model with same geometric properties. The 3-dimensional physical CUBE provides direct manipulation and tangible representation of architecture geometry.

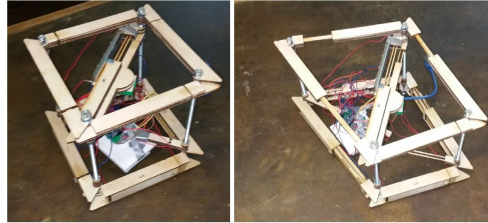


Figure 12
Collaboration Cube

Currently, CuBe can achieve 4 main functions:

Building Information Storage,

Since CUBE is an abstract physical representation, when doing massing study, designers may need to pay attention on architectural properties of the 3d volume such as area, height, number of stories. The feature allows designer to pre-associate those data and information with the geometry. As the designer is manipulating the geometry, these architectural properties will be automatically projected on the interactive desktop. So designer would have an intuitive impression about the building. Even designer moved the geometry, the property information will stick with the static geometry. (Figure 13)

Shadow Analysis

Shadow analysis is also possible. The system will generate a digital shadow based on the location of the building and the position of sun. The simulated shadow is also dynamic. User can set one of the static geometries as the shadow input parameter. Manipulation the input geometry dynamically simulates the whole day shadow situation. Using transformable twisting block, designer could evaluate the shadow impact from the shape changing. The system would sense the motion of twisting block and automatically updated the shadow in the real time. (Figure 14 & Figure 15)

Wind Analysis,

The function allows the user to evaluate the impact of wind to the building surrounding area by projecting a flow field on the tabletop. Once designer move or rotate the geometry within the interactive desktop, the

wind vectors will be automatically updated, and generate visual pattern for designer's judgement. (Figure 16)

Figure 13
Building
Information Storage
with CuBe System

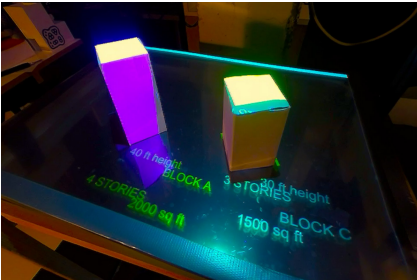


Figure 14
static geometry
shadow analysis

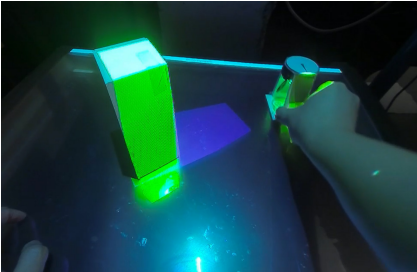


Figure 15
transformable
twisting block
shadow analysis

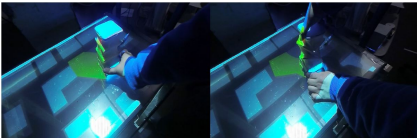


Figure 16
Wind Analysis of
CUBE

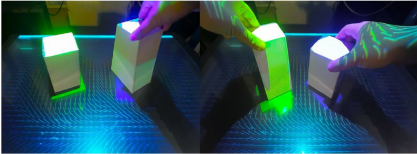
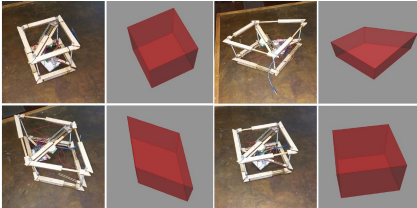


Figure 17
comparison of
transformable
physical model and
reconstructed
digital model



Collaboration

Shapes can be combined and manipulated while talking with a client or co-worker in consideration of a site condition. When the discussion is done, the model is immediately available. It is not necessary for the designer to recapitulate the modeling decisions. (Figure 17)

SUMMARY AND FUTURE WORK

In this paper have introduced two interactive 3D architectural design system prototypes called InSpire, and CuBe. These prototypes allow users to directly interact with virtual or physical 3D objects using natural or pre-set hands gestures. We described the system implementations, focusing on the workflow for developing gesture interactions. We illustrated several interactions that these prototypes support, and described application scenarios and possible uses.

We summarize the paper's contribution as follows: Developing several system allowing for 3D geometry to be created and manipulated through interactions based on user gestures, while leveraging the affordances of enhancing the visual experience or providing haptic reference and good hand gesture to approach appropriate fully 3d working environment. This research highlights that it is possible and helpful for designers working in a total 3d environment.

The study space of designer oriented physical media remains partially unexplored. The paper is attempting to establish an understanding of the space as well as develop several system prototypes which could embody the vision we seek to explore. The invention of physical design media will potentially completely change the traditional workflow of designers and bring them brand new working experience.

The research complete thus far indicates that the study of physical design media will not be wholly accomplished, understood, and delivered within either the domain of design study, or the domain of HCI. Instead, the work proposed resides in the connection between multiple areas - an interdisciplinary en-

vironment that is necessary condition to support.

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