A TANGIBLE MODELLING INTERFACE FOR COMPUTER-AIDED ARCHITECTURAL DESIGN SYSTEMS

DR. SURAPONG LERTSITHICHAI
Faculty of Architecture, Silpakorn University
Na Pralarn Rd. Bangkok, 10200, Thailand.
lsurapon@su.ac.th

Abstract. Computer-aided architectural design (CAAD) systems have been widely adopted in the architectural practice to improve and speed up late design phases. However, CAAD has not been successfully implemented in the early phases of design due to the overly structured nature of interactions with its interface. Current CAAD interfaces leave little room for intended ambiguity crucial to design conception and can cause obstructions to spontaneous creative thought. This research hypothesizes that architects employ tangible interactions to assist design-thinking tasks in early design phases. In doing so, architects can lessen visual overload and exploit underutilized motor skills and hand–eye coordination lacking in most CAAD systems. With this premise, a new CAAD interface is proposed, prototyped, and evaluated to validate the hypothesis. The new interface can retain functionality and accuracy of a CAAD system while also benefiting from ambiguous freehand input directly from users. This can greatly improve the interaction between designers and current computer-aided architectural design systems.

1. Introduction

Many architects today use computers extensively as a drawing or representation tool during the late phases of design rather than a design tool and medium during the early phases (Lawson, 1994). It is clear that the most advantageous function of a computer is being able to carry out long sequences of well-defined operations with accuracy and speed (Reynolds, 1987). This is common for drawing documentation and specification tasks. However, the early design process such as conceptualization and visualization where design is used solely for the purpose of communicating the architect’s ideas has not been successfully implemented by CAAD systems (Stappers & Hennessey, 1999). For early design tasks, CAAD applications are actually counter productive and usually slow down the creativity of the architect (Pollalis, 1994).

Primarily, this is so because current CAAD systems consist of overly structured and overly precise interactions that leave little room for expressive techniques such
as intended ambiguity or uncertainty that diminish most of the creative opportunities in design (Herbert, 1993). During an iterative design process, every step that is evaluated may lead to new steps and new alternatives to a better solution (Mitchell, 1989). Architects explore these design possibilities by sketching and drawing or by building physical models which are fundamental characteristics of graphic thinking (Herbert, 1993). Whether making drawings or models, the design process demands ambiguous and uncertain interactions from the architect’s hands and not predetermined or structured input from CAAD systems. Interruptions during these steps may obstruct the flow of concentration and block spontaneous creative thinking crucial to early conception of a design.

Moreover, current computer-aided design (CAD) devices and software applications are still confined to the graphical user interface (GUI) analogy. Their unfamiliar interactions require users to adapt towards the computer’s design convention rather than the architect’s convention. Consequently, architects and designers tend to prefer conventional paper sketches and physical models to the less user-friendly CAAD system.

2. Related Work

Most CAAD applications are 2D drawing and 3D modelling software that focus on the creation and manipulation of well-defined geometry. Each application has its own set of rules and operations that require a high learning curve especially for users who are computer illiterate. Operating these CAAD applications can be time-consuming and cumbersome especially during early design conceptions. Recent research in human–computer interaction has a more user-friendly look and feel to its interface and interactions. One of these interfaces called the “tangible user interface” (TUI) attempts to lessen this burden by introducing direct manipulation of physical objects that are coupled with digital information as an intuitive way to interact with computers (Ishii and Ullmer, 1997).

A specific type of tangible user interface that has been continually researched and adapted towards the use in CAAD systems since the late 1970s is the “computational construction kit” or “CCK” (Aish, 1979; Anagnostou et al., 1989; Anderson et al., 2000; Frazer, 1994; Kitmura et al., 2001). CCK for geometric modelling employs building blocks with embedded computer chips that can self describe their geometric structures in which they are assembled directly to a computer as a 3D visualization. These kits rely on the already familiar skill of building structures with building blocks so users can express 3D geometry without the knowledge of CAAD operations. This research attempts to revisit the CCK concept specifically on the redesign of the individual block and explores possibilities in integrating them into a new CAAD interface.
3. A New CAAD Interface

This research hypothesizes that architects employ tangible interactions such as sketching and modelling during early phases of design for design thinking. New human–computer interaction techniques such as tangible interfaces and CCKs can incorporate these interactions and direct ambiguous intentions to CAAD systems seamlessly. In order to validate this hypothesis, a proof-of-principle prototype is proposed and developed. The prototype design calls for an interface that employs intuitive physical interactions similar to interactions with conventional design tools and medium while retaining CAAD functionalities to increase the level of accuracy from direct user input. The prototype should also serve as an input device for CAAD systems that assists architects in the process of shape and form exploration similar to creating models with building blocks in CCK systems. Users should be able to manipulate the system as if it were a physical design medium and should be able to combine, subtract, and reshape the modules effortlessly before exporting and finalizing the design in a CAAD system.

4. Prototype Design and Implementation

4.1. INTERACTION DESIGN

The interaction design of this prototype system is based on the idea of an interface that acts both as an input and output device for user interaction. In other words, the interface and the medium are combined as a hybrid device. With this premise, the interaction cycle can be initiated when interactions with either the tangible or graphical user interface are detected. Next, user input is verified and interpreted by the system. Once the appropriate action has been determined, the system initiates the output which will be synchronized in both interfaces.

4.2. INTERFACE DESIGN

The prototype proposed in this research is called a “tangible modelling interface” (TMI) named after its user interaction technique and its general purpose for 3D modelling. It is a multi-modal interface that consists of both tangible and graphical user interfaces (Figure 1).

The prototype focuses on the task of modelling for shape and form exploration with tangible interactions. Users may use this prototype to physically create and manipulate three-dimensional geometry directly to the computer with their hands. The actual prototype is a single unit of a much larger modular entity. Each unit has self-contained interactive mechanisms and when combined, will react upon user interaction as a larger unified interface with higher physical resolution. However,
the latter approach has not been explored in this prototype due to limitations of time and resources.

The tangible interface is a single unit wire frame cube expandable from 4.5 to 6 inches in three separate axes (Figure 2). The cube dimensions were determined by the scale of an object suitable for grasping and manipulating with a hand. Its hardware consists of three systems: a push and pull system, a feedback system, and a micro-controller unit. The mechanism behind the push and pull system is a servo connected to mechanical arms that retract and expand when activated by two switches beneath two opposite graspable faces. The feedback system consists of sound from an internal buzzer and light from bi-colour LEDs attached to all faces of the cube. The sound is activated each time the cube has been manipulated to its peak moving positions. The lights are lit green when two faces are pushed and red when they are pulled. The micro-controller unit consists of a Basic Stamp II chip that controls all servos, switches, and LED lights and communicates with the computer via a serial RS-323 connection.

As shown in Figure 2, the GUI is an interactive 3D cube with a minimal set of
interactions and displayed elements. The 3D cube is a Java Swing program that exchanges data with the Basic Stamp program in the micro-controller to update its 3D graphic display. Once the program detects input from user manipulation to the physical cube, it sends commands to the Java program to update the display in real time (100 milliseconds delay). In general, the GUI is set to have a lower interaction priority but is able to manipulate the physical cube by changing configurations of the 3D cube or the attribute sliders in its interface hence the bi-directional interaction. However, the position and orientation of the 3D cube do not correspond to the physical cube in actual space and are not detected.

4.3. CREATION AND MANIPULATION OF OBJECTS

A 3D cube is automatically visible on the computer display when both prototype interfaces are activated. The 3D cube can be manipulated simply by pushing or pulling the physical cube or 3D cube. Only one axis can be manipulated at a time and the maximum and minimum displacements cannot exceed the physical constraints of the cube frame. Creating 3D models by assembling multiple cubes can only be done physically and not virtually. Although this feature is not implemented in this prototype, it is nonetheless feasible in future implementations.

5. Prototype Experiment

5.1. EXPERIMENT SET UP

The equipment used to conduct the experiment is the physical tangible modelling interface and a laptop PC that are physically connected via a serial cable. The tangible interface of the prototype uses two-handed input from the participant while its graphical user interface uses one hand to operate a mouse or touch screen as input to the system. Since the proposed prototype system was only completed as a partial prototype, therefore the experiment has been set up to evaluate manipulations of a single unit. Each participant is briefed about the system and its operations, then asked to performed simple tasks with the different interfaces of the prototype system.

The tasks in the experiment include: (i) manipulating the tangible interface, (ii) manipulating the graphical user interface, and (iii) manipulating the combined tangible modelling interface. The tasks consist of stretching and compressing the physical and 3D cube in one axis and all axes. With no prior instructions on how to operate the interfaces and with no particular order of tasks, participants must rely on intuition to determine proper user interaction to each and every interface. After completing the tasks, participants are then asked to fill a questionnaire to evaluate the prototype system from their experience.
5.2. EXPERIMENT RESULTS

Initial user feedback was limited yet constructive. With the comparison between the two interfaces, the results reveal that the tangible modelling interface was most favourable to users. Collectively, users provided common explanations that (i) the interface is more intuitive to use, (ii) is preferable for form explorations, and (iii) provides transparent interactions. The experiment also revealed patterns that contribute to the effectiveness of the interface design, namely that: (i) tangible interactions require less interaction cues and feedback compared to graphical user interfaces, (ii) consistency in the tangible interface determines the intuitiveness of the interface, and (iii) design conventions and prior experience in CAAD systems increases the usability of the interface. Participants were also asked to describe the features of the interface(s) that they disliked. Most complaints came from the construction limitations of the physical cube and the inconsistency of interaction cues and feedback between the physical and virtual representations.

6. Conclusion and Future Work

The prototype system is a tangible modelling interface that supports user interaction by means of tangible input to physical cubes to derive rough geometric models. This provides architects with an interface to CAAD systems that is more natural and less time consuming. Geometric models created by this system can be further enhanced by other CAAD applications in later design processes for refinement or analyses. The complete prototype system had not been fully implemented into a multiple unit assembly as initially planned. Although the single unit prototype is fully functional, its properties and functionalities are still very limited.

There are many directions to further refine the idea of the new CAAD interface. One direction can be taken towards a complete suite of CAAD interfaces, i.e., wire-framed, surface modelling, and volumetric interfaces. Another direction is to extend the application of the hybrid interface for purposes other than geometric modelling. For instance, it may be useful for simulation purposes in mechanical engineering to test motions and movements of various design configurations of a machinery part.

Finally, it is important that the interface be compatible with other CAAD systems or become a transitional modelling environment before exporting designs to other CAAD systems. In both cases, compatibility issues need to be concretely established.

Acknowledgements

The author would like to acknowledge contributions by Mathew Seegmiller, experiment participants, Jeffrey Huang, Spiro Pollalis, and Maribeth Back.
References