A HYBRID DIRECT VISUAL EDITING METHOD FOR ARCHITECTURAL MASSING STUDY IN VIRTUAL ENVIRONMENTS

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Abstract. This chapter presents a hybrid environment to investigate the use of a table-prop and physics-based manipulation, for quick and rough object creation and manipulation in three-dimensional (3D) virtual environments (VEs). A set of new direct visual editing techniques were designed to model virtual objects. The system has been integrated into a Cave Automatic Virtual Environment (CAVE) and a large screen display called GeoWall to address early architectural design called massing study. Experimental results demonstrate the following findings: (1) the physical prop for the CAVE and the GeoWall is an effective way to interact with VEs, at least for the tasks that have been studied; (2) architects can quickly model virtual building masses using our techniques; and (3) physics need to be combined with constraints in order to be effective.

Keywords. hybrid environment, computer-aided massing study, physics-based object manipulation, interactive 3D immersive environment, direct visual editing.

1. Introduction

Achieving content creation and modification is a major goal of immersive design and has its potential to have broad impact on architecture, mechanical engineering, and automobile industries. One of the content creation tasks is called massing study. A scenario of use is similar to the following: compose a building according to a particular shape and style and then construct a mass. The conventional practice is to cut cardboard or shape clays to construct physical miniature mock-ups. Unlike other modeling systems, the purpose is not to draw fine delicate strokes but to examine shapes and forms.

One obstacle remains to accomplish massing tasks in immersive virtual environments (VEs). There is a lack of easy-to-use rough and quick content creation. Several 3D immersive design tools (see Deisinger et al., 2000 for a summary) allow for direct manipulation on shapes and forms. However, for the environments that are represented with only one scale, directly editing 3D scenes could introduce a performance penalty due to transitional costs between the large view (for editing) and the overview (for checking forms and shapes). Such transitional costs for interaction may cause fatigue associated with spatial input (Hinckley et al., 1994).

Advances in modeling and rendering notwithstanding, designers continue to favor their conventional studio style for massing study. A VE appeals as an artistic medium to show objects at multiple scales. What is needed is a seamless transition from architects' office to immersive design environments. Such a transition should be further augmented rather than hindered by non-conventional input devices to make massing tasks more efficient and effective, as compared to the physical one. This is precisely our focus in this chapter.

The challenge for the design of the 3D massing study system lies in interaction. An issue is to find an appropriate mapping from high degree-of-freedom (DOF) input devices to high DOF modeling tasks that would minimize user's attention on user interfaces. Though direct manipulation within a VE on architectural modeling remains by far the dominant interaction paradigm, we propose a hybrid environment and gesture-based direct visual editing method (see Figure 1) (Chen, 2006). Rather than operating on widget, direct visual editing merges command input and actions on objects to eliminate the extra level of widget input abstraction. The transitions between actions are smooth and the UI (user interface) supports close-body interaction in a relatively small working volume. Our system automatically interprets a command according to the handedness, number of objects grabbed, and motion of the user's gesture. Using our techniques, the user can scale, move, rotate, quickly stack, align, delete, and retrieve architectural elements. Both a miniature view and a large one-to-one scale scene are presented to reduce the transitional cost between views.

This chapter presents the design and results from a user study, the present study of using a hybrid system and 3D direct visual editing can serve as a useful guide and starting point for the community of designers and practitioners who wish to investigate rich design space for modeling.

Figure 1. A hybrid massing study environment coupled with a large screen display (GeoWall, left). In such an environment, the two hands function differently. The non-dominant hand wears a pinch glove for imprecise and quick input and the dominant hand holds a stylus pen to conduct relatively precise object manipulation. The hybrid system also works in the CAVE with a miniature view displayed on the tabletop (the right image).

2. Related Work

Content creation is one of the most important challenges in computer graphics and immersive modeling. Most immersive conceptual design systems (Bowman, 1996; Deisinger et al., 2000) use a menu for primitive creation, alignment, selection, and reshaping and operate on a large design space. Our design removes the menu selection step and instead uses 3D gesture input because merging command and object selection could improve task performance (Guimbretière et al., 2005).

Tangible user interfaces (TUI) simulate architectural desktop environments to allow architects to draw directly on paper using digital or regular ink or using sensors to push and pull a model (Lee et al., 2006). This provides excellent haptic feedback. One difficulty of using such a system for massing study, however, is to undo or delete objects. Other immersive design systems make use of domain specific characteristics to design interaction for immersive tasks (Underkoffler and Ishii, 1999; Chen et al., 2004). We share the same goal in capturing domain characteristics in the design process, however, we design interaction for the massing tasks that impose different design requirements, which have not been sufficiently studied.

There are techniques and tools that support conceptual design by editing two-dimensional (2D) inputs to construct three-dimensional (3D) structures. One method is to use free handing sketching recognition (Zeleznik et al., 1996; Schkolne et al., 2001). This method has low overhead in representing, exploring, and communicating geometric ideas. It is analogous to using physical pencil and paper, which are probably the best tools to illustrate design ideas, despite that recovering 3D shapes from 2D drawing is challenging (Chen et al., 2008). Teddy and its extensions allow users to draw curves and support many other operations, such as extrusion, cut, erosion, and bending for modification purpose (Igarashi et al., 1999), though the systems are limited to making blob style objects.

An alternative modeling method is to sketch directly in 3D. The main approach is to operate on 2D shapes to derive the 3D ones using constraints (SketchUp, 2008). For example, SESAME advances the design by minimizing the 2D input mode and facilitates efficient drawing with suggestions, automatic segmentation, and recognition of closed structures (Oh et al., 2006). Our work tries to achieve the same goal but emphasizes direct 3D editing, so that designers do not have to translate 2D drawings into 3D in their minds. In addition, our system is designed for immersive displays, which could incur the change of gesture grammar.

3. Designing for Massing Study

In order to design an effective massing study environment, we started with analyzing prior work and consulting architects to learn the design requirements. We interviewed professionals in architectural firms and people from the architectural department on campus to elicit design requirement. We asked questions about current practices and conventional workflows, and pros and cons of existing modeling tools. Finally, we obtained important design elements in the massing study process and identified a set of principles for interactive content creation.

3.1 ROUGH AND QUICK CONTENT CREATION

The purpose of massing study is not to draw fine delicate strokes to indicate detailed structures, but rather to apply a series of well-established architectural elements for making mock-ups. Architects make frequent remodelling, reconstruction, design comparison, and the addition and removal of clay or cardboard masses. Box, sphere, pyramid, stairs, and bars are basic shape elements (Hohauser and Demchyshyn, 1984). Objects in the scene should be solid models.

3.2 VISUAL CONTEXT AND MULTIPLE SCALE VIEWING

When creating objects, architects like to play with shapes and their spatial layout. They then place the finished design in the surrounding context to examine the form. Architects prefer to examine their design in a one-to-one scale. In our design, we present both a miniature and a one-to-one scale view. The miniature view shows the objects being edited. The real scale view includes alternative designs and surroundings. We choose to have two views also out of design considerations for 3D UIs. Operating in a close-body fashion can also reduce fatigues (Hinckley et al., 1994) and increase input precision (Zhai et al., 1996).

3.3 ERGONOMIC REQUIREMENTS

One major drawback of current VE design is the ergonomic issue. Users will not use a system that requires standing posture, lacks arm-resting positions, and exploits precision fine motor skills.

4. System Overview

To address users' requirements, we built a hybrid environment by integrating a table prop to the conventional immersive or semi-immersive VEs. A table prop is integrated in a 10'x10'x10' CAVE or in front of a large screen display, called Geowall (Consortium). The table is transparent made out of acrylic glasses and thus does not block the user's view. It is tracked with a Polhemus FastTrak, therefore becomes an active interface component. While coupled with the CAVE, a virtual table was rendered at the same location as the physical table. Widgets and miniatures of the virtual scene can therefore be displayed on the physical table. The peripheral vision provided by CAVE or a large display presents the context of the design in a one-to-one scale.

The idea of using the table-prop was driven by two considerations: one for the architectural domain of use and the other for the interactivity. The table utilizes architects' familiarity with drafting on their workbench and naturally divides the design space into two areas, one on the table (a miniature view) and the other in the immersive VE (a one-to-one scale).

The table prop could support precise object manipulation and close body interaction to avoid performance loss due to the lack of a physical surface to touch with free hand manipulation. Close-body two-handed manipulation techniques can improve task performance and precision of interaction by providing proprioceptive cues and reduce repetitive actions by operating on miniatures. The table also shares the benefits of passive haptic feedback similar to the pen-and-tablet metaphor user interface, and frees the user's non-dominant hand for other operations.

A tracked pinch glove and a stylus pen are integrated to support asymmetrical two-handed manipulation. The user will hold the pen in his or her dominant hand and wear the glove in his or her non-dominant hand. By doing so, users can perform both tasks requiring imprecise but quick input (e.g., grasping) using the glove and tasks requiring fine operations using the stylus. Our interaction design is intended to support direct visual editing with gesture input.

5. Direct Visual Editing Techniques

We define direct visual editing as the type of direct manipulation in which a user's action is applied to visual objects using gestures rather than widget input. We differentiate this method with other direct manipulation such as widget-based direct manipulation of visual content, in that direct visual editing merges command selection and object manipulations. Such a merger has shown its benefits in 2D menu manipulation because the interaction reduces the access cost of the menu system.

5.1 OBJECT CREATION

One way to create object is to use what is called copy-by-example (see Figure 2). Every object that has been placed in the scene can be copied. Our interaction technique directly maps the orientation of the user's hand to the system actions. The user points the index finger horizontally (+/- 45 degree error permitted) and then pinches index finger and thumb to create a copy. The finished copy is attached to the user's hand. This action is similar to pulling another object out of existing ones. Any objects, including grouped objects, can be created in this manner.

The advantage of copy-by-example is that it simplifies the architect's workflow. Rather than building a structure from scratch, the user can generate a copy of a structure and work from there to construct a similar one. This operation is useful to build alternative designs, when many similar parts exist.

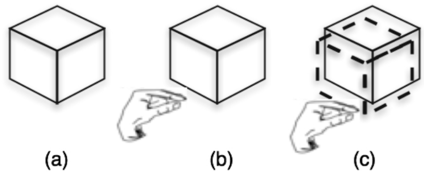

Figure 2. Copy by example. (a) Original state. (b) The user moves his / her hand closer to the object and the index finger is near horizontal to the supporting plane. (3) The user pitches the index figure and thumb to create an object.

5.2 OBJECT MANIPULATION

Another single-handed operation is manipulation (see Figure 3). The system uses the grasping gesture, i.e., downward direction from the output of the tracker attached to the pinch glove (+/- 45 degrees error permitted). To make the grasping easier, no "virtual touch" is required. A threshold of 10 cm distance can activate the "grab" action. An alternative way to move an object is to use the hand to grab and move. Users can also pass an object from one hand to the other.

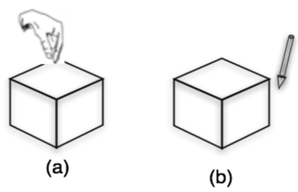

Figure 3. Single-handed manipulation gesture. (a) Grasping using the tracked glove. No direct touch is needed. The system defines the action based on the direction of the hand. (b) Moving using the stylus.

5.2.1 Single axis scaling and rotation

Scaling and rotation make use of two-handed manipulation (see Figure 4). The user places his or her two hands on each side of the selected object. Only one axis of rotation or scaling is enabled to reduce the degree-of-freedom of the spatial input. The center of the rotation and scaling is the origin of the local coordinate system. The axis of rotation is perpendicular to the rotational plane of the two hands. The system automatically chooses rotation or scaling based on the relative motion of the two hands. When the distance between two hands is larger than the rotational distance, the system will scale the object, otherwise, a rotation command is issued.

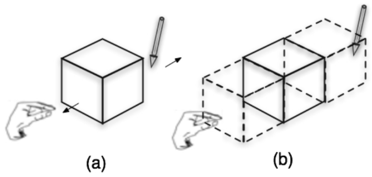

Figure 4. Scale object. (a) Arrow indicates the moving direction of the user's hand. (b) The object is scaled as a result of the movement. If the relative motion is rotation in (a), the object will be rotated.

5.2.2 Boolean operations

Similar to scaling and rotation, the Boolean operation utilizes two hands (se Figure 5). Three Boolean operations are supported: union, difference, and intersection. This command is activated when each hand pinches and grabs an object. The object in the right hand will be the operand. Once two objects are grabbed, the system automatically changes to the Boolean state. Therefore, the user does not need to keep the index finger and thumb pinched in order for the object to remain grabbed.

The user pinches the index and the middle fingers to shuffle between Boolean operations. A preview shows the results of the Boolean operation at run time. Pinching ring finger and thumb will also enter the preview model and disable Boolean operation. Clicking the stylus button will complete the current operation. Boolean operation can also be performed in place using the objects grabbed in the user's right hand by pinching the index finger and thumb (with no object selected).

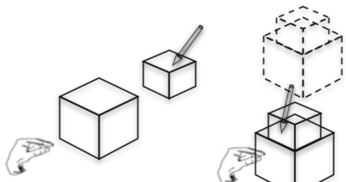

Figure 5. Union and subtraction of any shapes. (a) Grabbing an object in each hand will activate the Boolean command. (b) Union, what you see is what you get. A preview is shown to draw the result.

5.2.3 Off-the-table deletion and retrieval

Users can “push” the object off the table to delete it. The object will be placed on the “ground”. This placement does not need to be precise because objects behave according to physics laws. The object will fall due to gravity until it hits another surface, such as the physical floor in the CAVE. To retrieve the object, users use a ray-casting technique to grab the object; the object is animated to the pen-tip and can be placed back onto the tabletop.

This technique can provide easy object composition, deletion, and retrieval by declaring the table-prop the current working place. All other places can be considered as an extra storage space. The action is similar to throwing garbage into a trashcan on the floor. Users can also use this method to save the table space by placing extra objects on the floor.

5.3 PHYSICS

We implemented constrained physics-based manipulation. Three types of physical behaviors are supported: kinematics interaction, collision detection, and gravity. Kinematics interactions involve one object’s motion that constrains or affects the position and orientation of another object at some connection point or joint. Collision detection prevents objects from penetrating each other while positioned. Objects having gravity allows causal placement of an object on top of another.

These physical behaviors can allow the architect to predict how objects move relative to each other. Physics-based manipulation can help rough placement of objects in space, as positioning in six (DOF) simultaneously is still difficult even with all the benefits from the constraints provided by the table-prop. For example, objects can float in space or penetrate each other, and making virtual objects touch and align is not easy.

The system automatically turns off the kinematics constraints when an object is grabbed and turns it back on when the object is released. Therefore, objects can penetrate each other during maneuvering in our current implementation. This design decision was made after a pilot study, where we found that full physics did not work well for object manipulation, because the existing structure could be toppled if a large object was picked up and accidentally hit the pre-built structure. While this “accidental” hit might not happen in the physical world, it happened quite often in the virtual world possibly because virtual objects did not provide tactile feedback and they were virtual, hence unable to convey their physical behaviors.

5.4 MODELING WORKFLOW

One major contribution of our work is enabling complete visual editing of mass quickly. We will show a case study of creating a simple building from scratch. To create a more complex building such as the middle one in Figure 6, middle, the user would need to perform the following actions: (1) grabbing a virtual box from the knapsack and resizing to the desired dimensions; (2) grabbing another one with stylus pen and performing a Boolean operation to create the hole and place it on the table; (3) grabbing and scaling several more boxes to stack them together to form the building up front; (4) grouping the mass by clicking the lock button on the bottom right corner of the table; and (5) rotating the block to the desired orientation.

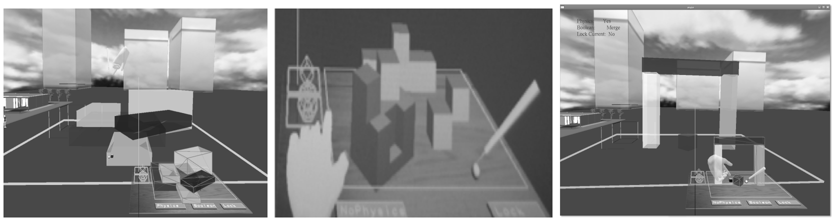

Figure 6. Example scenes created using our system

6. Usability

We conducted an exploratory user study to examine the usability of our designed system and techniques. Constrained by the page limit, we only report major results. At a higher level, we wanted to learn overall subjective responses to the design of the table-prop, physics, and direct visual editing methods. All participants were positive about using the table and the seated condition. Major results include the following.

Firstly, the physical table warrants passive haptic feedback and close-body interaction that are well suited for the massing study, at least for the tasks we measured. When users acted at the table level, the table-prop helped stabilize their hands and served as an anchor surface for transformation or rotation. However, the table-prop did not help with the upper level construction when participants tended to move their hands much higher than the table.

Secondly, the table surface increases the stability of users' hands, reduces excessive effects of undesired input actions and enables fine movement at the finger level. 2D WIMP and 3D interaction were permitted.

Thirdly, physics-based direct visual editing provides effective scene composition. Full Newtonian physics might not be a good option for VEs. Instead, constrained physics work better. Physics hindered some user tasks. One user commented that architects sometimes build models from top to bottom. Physics-based UI would not allow him to do so because objects tend to fall onto the desk though it is consistent with what could happen in a design studio. One solution is to lay the space on top of the drafting table to define different levels of operation.

7. Conclusions

This chapter presents our experiences in the design and evaluation of a hybrid virtual environment system and direct visual editing techniques for architectural massing study. The chapter contributes (1) the design of a hybrid environment for massing study interaction and an exposition of the underlying design rationale, (2) advancement to direct visual editing techniques, and (3) design experiences and modeling method.

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References

Bowman, DA: 1996, *Conceptual design space - beyond walkthrough to immersive design*, *in* D. Bertol (ed), Designing Digital Space, Wiley, New York, pp. 225-236.

Chen, J: 2006, *Design and Evaluation of Domain-specific Interaction Techniques in the AEC Domain for Immersive Virtual Environments*, unpublished PhD dissertation, Department of Computer Science, Virginia Tech.

Chen, J, Bowman, DA, Lucas, JF and Wingrave, CA: 2004, Interfaces for cloning in immersive virtual environments, *Proceedings of Eurographics Symposium on Virtual Environments*, pp. 91-98.

Chen, X, Kang, S, Xu, Y-q, Dorsey, J and Shum, H-Y: 2008, Sketching reality: realistic interpretation of architectural design, *ACM Transaction on Graphics,* **27**(2).

GeoWall Consortium, http://www.geowall.org/, accessed in May 2009.

Deisinger, J, Blach, R, Wesche, G, Breining, R and Simon, A: 2000, Towards Immersive Modeling - Challenges and Recommendations: A Workshop Analyzing the Needs of Designers, *Proceedings of Eurographics Workshop on Virtual Environments*, pp. 145-156.

Guimbretière, F, Martin, A and Winograd, T: 2005, Benefits of merging command selection and direct manipulation, *ACM Transactions on Computer-Human Interaction (TOCHI),* **12**(3): 460-476.

Hinckley, K, Pausch, R, Goble, J and Kassell, N: 1994, A survey of design issues in spatial input, *Proceedings of ACM symposium on User interface software and technology*, pp. 213-222.

Hohauser, S: 1984, *Architectural and interior models*, Van Nostrand Reinhold.

Igarashi, T, Matsuoka, S and Tanaka, H: 1999, Teddy: a sketching interface for 3D freeform design, *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, pp. 409-416.

Lee, CH, Hu, Y and Selker, T: 2006, iSphere: a free-hand 3D modeling interface, *International journal of Architectural Computing,* **4**(1): 19-31.

Oh, JY, Stuerzlinger, W and Danahy, J: 2006, SESAME: towards better 3D conceptual design systems, *Proceedings of ACM Designing Interaction Systems (DIS)*, pp. 80-89.

Schkolne, S, Pruett, M and Schroder, P: 2001, Surface drawing: creating organic 3D shapes with the hand and tangible tools, *Proceedings of ACM Conference on Human Factors in Computing Systems (CHI)*, pp. 261-268.

Google SketchUp: 2008, http://sketchup.google.com, accessed in May 2009.

Underkoffler, J and Ishii, H: 1999, Urp: a luminous-tangible workbench for urban planning and design, *Proceedings of ACM Conference on Human Factors in Computing Systems (CHI)*, pp. 386-393.

Zeleznik, RC, Herndon, KP and Hughes, JF: 1996, SKETCH: an interface for sketching 3D scenes, *Proceedings of SIGGRAPH*, pp. 163-70.

Zhai, S, Milgram, P and Buxton, W: 1996, The influence of muscle groups on performance of multiple degree-of-freedom input, *Proceedings of the conference on Human factors in computing systems (CHI)*, pp. 308-315.

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