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StandUp: Understanding Body-Part and Gestural Preferences for First-Person 3D Modeling

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Abstract

There exists interfaces for 3D modeling that go beyond traditional keyboard and mouse input techniques. This paper takes a first-person paradigm of 3D modeling where a designer actively employs different body parts as part of the user interface. Specifically, we explore the body parts and corresponding gestures that users prefer for various primitive 3D shape creation and 3D manipulation tasks. Also, we investigate how virtual primitive shapes and physical primitive objects augment gestures and affect user preferences when modeling 3D shapes. The results from our study provide suggestions to guide the design of interfaces using different body parts and gestures for first-person 3D modeling.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Information Interfaces and Presentation]: User Interfaces—Interaction styles; I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Modeling packages

1. Introduction

To ease the creation and manipulation of 3D shapes, a number of alternatives have been proposed including: sketch-based interfaces [IMT99, OSSJ09, YNL09], hand gesture based interfaces [HW11], and mixed-reality interfaces [WLK*14]. The motivating concept of this work is that if a user wishes to model a 3D virtual shape that is eventually to be manufactured into a physical object that will interact directly with the user and the real-world environment, we should build user interfaces that actively involve the user's whole body. In this paper, we advocate the idea that the user's own body is an essential part of the user interface medium. We take a first-person 3D modeling approach where the user actively "stands up" in the real-world environment and model 3D shapes directly with parts of his/her own body.

We describe an example application scenario for our first-person 3D modeling approach. A user stands in an empty room of his/her home and wishes to model various furniture items. The user walks around in the empty space and performs gestures (Figure 1) to directly express the creation and editing of such virtual furniture shapes. While expressing the 3D shapes, the user takes important style, size, and dimension clues from the surrounding environment. In such a scenario, there are many possible actions that users can perform with their own bodies. Hence our assumption is that there is much to learn from investigating user preferences before any system is built. This paper thereby focuses on understanding user preferences for body parts and gestures for first-person 3D modeling. We use the term "first-person" to describe the idea that the user employs different parts of his/her body to directly act out operations in the real world. We do *not* focus on gesture recognition as there exists much previous work in this topic.

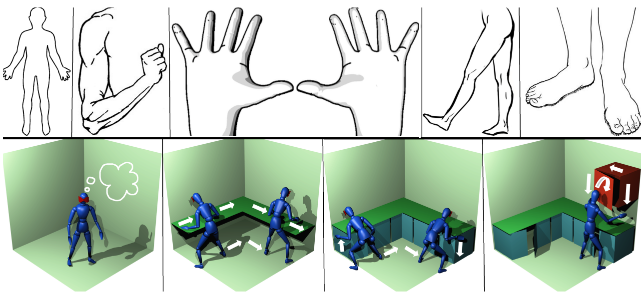

Figure 1: *First row: Different body parts that can be used as input for 3D modeling. Second row: Images showing an example application scenario to motivate our approach. A user stands in an empty room and starts by making gestures to describe the top parts of shelves that fit into the surrounding environment. The doors and sides of the shelves are then modeled, followed by a cabinet that attaches to the wall.*

Previous works that are closely related to our idea include 3D sketching with a wand-like tool [YNL09] and modeling in 3D space with tangible primitive shapes [LHO*12]. These existing systems are not for gesturing using different parts or combinations of parts of the human body. BodyAvatar [ZHR*13] allows a user to create

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coarse 3D shapes with body movements by standing in front of a Kinect device and is specifically for creating avatars. We aim to design interfaces where the user can actively think and gesture in 3D space, and use their preferred body parts as part of the interface for general 3D modeling. The target users of our modeling system are both the general public and professionals who intend to perform in-situ design with the flexibility of describing shapes using their body parts.

We focus on exploring the research questions of eliciting gestures from users and understanding the design of first-person modeling interfaces. First, as we take a first-person 3D modeling approach, we wish to understand the body parts and corresponding gestures that are preferred by users for modeling 3D shapes. We investigate the body parts and gestures for various 3D primitive shape creation tasks and 3D manipulation tasks. We find that across many tasks, gesturing with hands/arms is preferred compared to legs/feet and head/neck/torso. We also analyze the user movements to obtain a set of user preferred gestures for these tasks. Second, as gesturing in empty 3D space is difficult, we explore the additional use of virtual primitive shapes and physical primitive objects as guidance tools for the user. We observe users while they describe furniture items with such shapes. We find that physical primitive objects are preferred most often. However, the use of virtual primitive shapes and just gestures alone are equally good options, as there is no statistical significance to the user preferences for these additional tools. Third, based on the results of our studies, we develop suggestions and insights to guide the design of first-person 3D modeling interfaces.

The contributions of this paper towards first-person 3D modeling interfaces are: (i) an understanding of user preferred body parts and gestures for a set of basic 3D shape creation and manipulation tasks; (ii) a comparison between "gestures only", "virtual primitive shapes + gestures", and "physical primitive objects + gestures" approaches; and (iii) a set of suggestions to guide the design of these interfaces.

2. Related Work

We discuss related work in a number of areas and highlight the key novelties of our work.

Whole-Body Interfaces. Spatial Sketch [WLMI10] allows a user to sketch in 3D space to design a lampshade. It bridges between physical movement and fabrication as the designed shape can be fabricated as a real object. KinÊtre [CIF12] is an animation system that allows a novice user to virtually attach his/her limbs to geometry such as a chair model and create animations of it. Our work is closely related to the idea presented in BodyAvatar [ZHR*13] where users stand in front of a Kinect device and create free-form 3D avatars directly with their body movements. In contrast, this paper studies the user preferred body parts and corresponding gestures for a set of primitive 3D modeling operations.

Embodied Interactions. In the field of embodied cognition, researchers have claimed that bodily activity is essential to understanding human cognition [KHT06]. In human-computer interaction, researchers have explored using the body itself as an input interface [HTM10]. For computer games, some controllers (e.g. Wii Remote) allow for embodied interactions in the swinging of a tennis racket, baseball bat, or golf club. The action of swinging with a controller provides satisfactory experiences for the user. Dourish's book [Dou01] describes the trends of tangible computing in how our interfaces can be off the screen and into the physical world. These existing work inspired our concept of bringing the modeling process into the real-world where users can actively participate in 3D space. In many fields of study, the importance of embodied interaction is clear, and we apply this concept to 3D modeling in our work.

Gesture-Based Interfaces. Researchers have argued that the keyboard and mouse interface may restrict gestures and decrease physical mobility such that it is "likely to hinder the user's thinking and communication" [KHT06], especially for tasks that naturally requires physical interaction. Three-dimensional user interfaces [BKLP04] provide an alternative to the traditional keyboard and mouse input, and "gestural commands" are one type of 3D user interfaces. The concept of our work in exploring user preferred gestures is similar to gestures for surface computing [WMW09], but for a different problem of 3D modeling. There is work in human-computer interaction exploring gestural interactions with mobile devices (e.g. [RLL11]), but they are not for the application of shape modeling. For the purpose of 3D modeling, Surface Drawing [SPS01] uses hand gestures for drawing 3D shapes in space. Data Miming [HW11] investigates the use of hand gestures for describing and retrieving 3D shapes. MixFab [WLK*14] explores a combination of hand gestures and mixed-reality interfaces for modeling and fabrication. In our work, we explore not only hand gestures, but gestures using different body parts to describe shapes in a first-person environment.

Situated and Immersive Interfaces. Modeling-in-Context [LSMI10] uses a single photo as a reference for modeling new shapes. Sinha et al. [SSS*08] use multiple photos as a reference for modeling 3D architectures. Insitu [PKM*11] incorporates context for sketching architectural designs by including various input such as site photos, aerial maps, and elevation data. Furthermore, there are 3D interfaces that provide an immersive experience. Yee et al. [YNL09] demonstrate 3D insitu sketching with a wand-like tool. CopyCAD [FCLI10] takes real-world objects and incorporates them into the virtual world as part of the modeling process. Situated Modeling [LHO*12] provides tangible primitive shapes and uses an augmented reality framework to incorporate the existing environment and real-world objects during the modeling process. Tactum [GGF15] introduces a skin-centric approach that uses gestures performed on human skin to create shapes directly around the body. In this paper, we provide an immersive experience in the sense of a first-person interface. The user actively moves in real-world 3D space and performs gestures using any body part to create and manipulate 3D shapes in the same space.

The central aim of our work is to understand how users gesture using different body parts for first-person 3D modeling. The motivation is that, as seen from the related works above, this is an interesting type of embodied interaction for modeling that has not been explored.

3. Methodology

We describe the methodology of our user study in this section, and the results in the following sections. Our study explores recurring patterns in gestural descriptions using three tasks and a post-study questionnaire.

Task and Procedure. At the start of each study session, the participant answers two questions about his/her previous experiences in computer science and in 3D modeling software. The study comprises of three tasks. Before each task, the user is given a high-level description of the task.

Task 1: Shape Creation. In this task, our goal is to find the preferred body parts and corresponding gestures for a set of basic 3D shape *creation* operations. The participants were provided these shapes (Figure 2a): circular surface, rectangular surface, cone, cube, and cylindrical frame (i.e. frame shape consisting of three cylindrical rods). The shapes were shown to the participants on a sheet of paper and we also provide a human figure beside them to give an idea of the approximate scale. We selected these shapes as they are considered primitive shapes and can be used to create more complex shapes. Participants were then asked to perform the gestures to express each shape as accurately as possible using each of these body parts: “legs and/or feet”, “arms and/or hands”, and “head, neck, and/or torso”. The purpose here is to specifically test the effectiveness of each body part and hence the participants were asked to perform with each of these body parts for each case. The ordering of the shape descriptions was randomized for each participant. If the participant was unable to come up with a gesture for a particular operation and body part, he/she can select a “cannot do” option. After performing gestures using each body part, the participants self-rated on a Likert scale of 1 (strongly disagree) to 5 (strongly agree) on how well they think their own gesture describes the given shape. These self-ratings are intended to give us an understanding of the effectiveness of each body part (i.e. can the body part be used to perform the task?), and *not* for analyzing the effectiveness of the gestures themselves (i.e. will others recognize a gesture to correspond to a specific task?).

Task 2: Shape Manipulation. In this task, our goal is to find the body parts and corresponding gestures preferred by users for a set of primitive 3D shape *manipulation* operations. The participants were given images for these manipulation operations (Figure 2b): move from one place to another (table top at waist height), move from one place to another (surface on floor), rotate (surface on floor), scale up (surface on floor), cut (surface on floor), and bend (surface on floor). The images were provided on a sheet of paper. They were asked to perform the gestures to express each operation as accurately as possible using the body parts as in *Task 1*. The ordering of the operations was randomized for each participant. Participants were told not to take weight and material into consideration while doing a manipulation operation. They also have a “cannot do” option. After each gesture, they again provide a self-rating as in *Task 1* .

Task 3: Furniture Creation with Virtual/Physical Primitives. Our goal is to observe how users augment gestures with virtual and physical primitive objects for expressing the shapes of furniture items. The participants were asked to describe with gestures to create one of the following: a dining table, a bookcase, or a kitchen cabinet. They were to create the furniture item using three different ways: with only body movements/gestures (where participants were free to use any body parts for this task), with gestures and a set of virtual primitive shapes (Figure 2d), and with gestures and two physical primitive objects (Figure 2e). The virtual shapes were shown to users as images and their initial sizes were approximately the size of the human hand. For both the virtual and physical shapes, users were told that they can make “copies” of them in space. As the users cannot see the created shapes and can only imagine them, they were asked to speak out loud their gestures and intentions throughout the process. The user study room was selected such that it had space for describing the above items in order to facilitate insitu modeling. For describing the dining table, real chairs were provided such that a table was to be created to fit with them (Figure 2c). For the bookcase, we provided a specific space between two walls. For the kitchen cabinet, it was to be attached to a specific wall in the room. Finally, for each of the three methods, the participants gave a self-rating on a Likert scale of 1 to 5 on how well they think they were able to virtually create the desired furniture item.

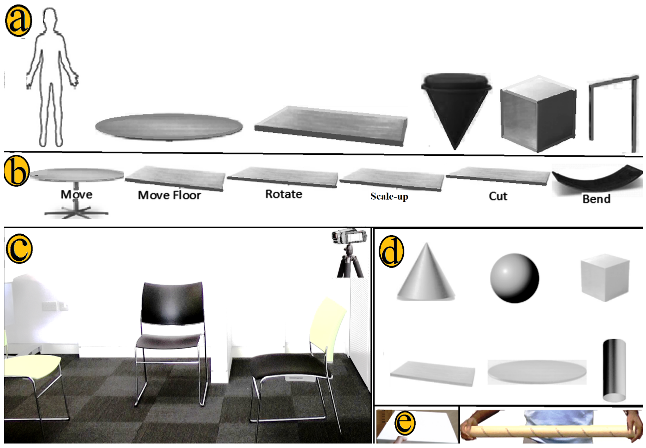

Figure 2: *User study setup. (a,b) Images used for Tasks 1 and 2 respectively. (c) Users were given an empty space for performing gestures, and also chairs as guidance tools for Task 3. We record the user's movements for later analysis. (d,e) Virtual primitive shapes and physical primitive objects (a rectangular piece and a cylindrical rod) for Task 3.*

Post-Study Questionnaire. This questionnaire was designed to understand the overall experience of the participants. We asked the participants to give comments about their gestures and tasks, the advantages and disadvantages of describing 3D shapes in sizes equivalent to nearby existing objects, and the advantages and disadvantages of describing 3D shapes in real-world space.

Apparatus and Participants. The user study environment consists mainly of an empty space to allow for user movement, with additional tools in *Task 3* as described above. In particular, the participants did not receive any visual feedback when they gestured to design or manipulate the virtual shapes. Hence they were asked to speak aloud throughout their thinking and gesturing processes. Instructions were given as text and images on paper and the participants gave their self-ratings on paper. Their thoughts and gestures

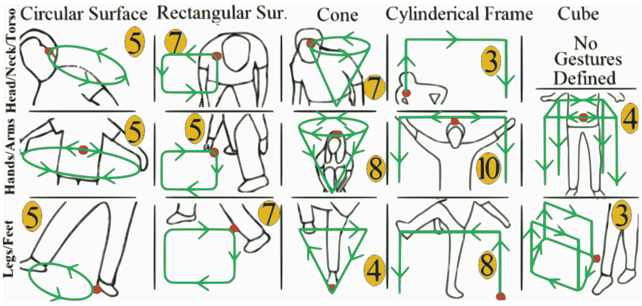

Figure 3: *User-Preferred Gestures for Task 1. For each body part and each 3D shape, the most preferred gesture among all users is shown (with corresponding number of users). The small red circle represents the starting point of each gesture. "No Gestures Defined" means the majority of users chose the "cannot do" option and hence we do not attempt to show a preferred gesture.*

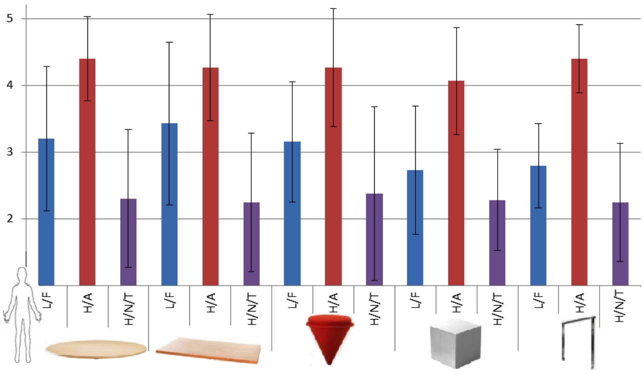

Figure 4: *Task 1 Results. Means and standard deviations of self-ratings for each 3D shape and each body part: legs/feet (L/F), hands/arms (H/A),and head/neck/torso (H/N/T).*

were recorded on video. Each study session took approximately 50-65 minutes. There were 15 participants (12 male and 3 female, each paid \$10) of mean age 28.3 (std 6.51) recruited from members of our university.

4. Results

In this section, we show the results for the three tasks. All participants reported having experience with computers in general, while only one participant reported having 3D modeling experience.

Task 1: Shape Creation. In this task, the total possible responses we can get is: 15 users x 3 body parts x 5 operations. Of these responses, 16% are "cannot do", which occur mostly for the head/neck/torso body part as this was the most difficult to gesture with in practice. For each body part and each shape, we show the gesture preferred by most users (Figure 3). The main result here is that **participants tend to use each body part as the drawing tool itself to sketch some wireframe approximation of the desired 3D shape**. The positioning and/or orientation of the shapes are sometimes ignored by the users. We interpret the self-rating as follows: the higher it is, the better is the body part and corresponding gesture for an operation. Figure 4 shows a summary of the self-ratings. For each of the five 3D shape creation operations, we take

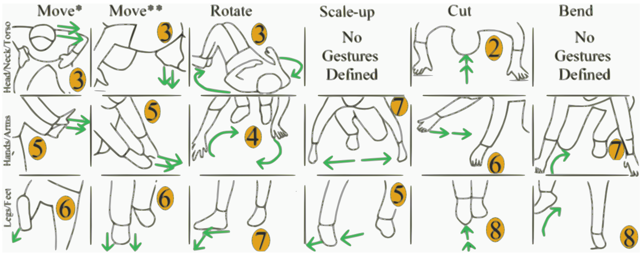

Figure 5: *User-Preferred Gestures for Task 2. For each body part and each manipulation operation, the most preferred gesture among all users is shown (with corresponding number of users). Here, Move∗ and Move∗∗ refers to move at waist height and move on floor respectively. Rest of the operations are manipulations on the floor.*

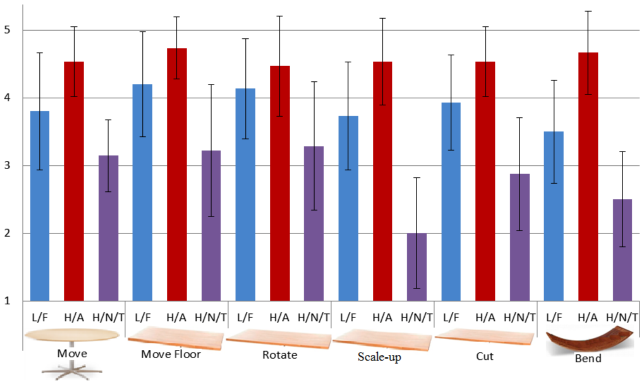

Figure 6: *Task 2 Results. Means and standard deviations of self-ratings for each manipulation operation and each body part.*

the ratings for the 15 users and 3 body parts and perform a one-way ANOVA. For all five shapes, the p-value is < 0.001 and hence the means of the self-ratings of the different body parts are significantly different. We then perform a Tukey's test for each shape. For the circular surface, comparing all three pairs of body parts (e.g. legs/feet vs. hands/arms is one pair) gives p-values of < 0.05. For the rectangular surface, the p-value of legs/feet vs. hands/arms is > 0.05, while the p-values of the other two pairs are < 0.05. For the cone, cube, and cylindrical frame, the p-value of legs/feet vs. head/neck/torso is > 0.05, while the p-values of the other two pairs are < 0.05. The overall result for Task 1 is that *gesturing with hands/arms is the most preferred and this is statistically significant* (except for the rectangular surface case where hands/arms and legs/feet are equally significant).

Task 2: Shape Manipulation. In this task, the total possible responses we can get is: 15 users x 3 body parts x 6 operations. Of these responses, 16.9% are "cannot do", which also occur mostly for the head/neck/torso body part. For each body part and each operation, we show the gesture preferred by most users (Figure 5). The main result here is that **participants use each body part as a physical tool for shape manipulation**: for example to use a body part to directly push, cut, or bend a shape as if the body part was the tool itself. Figure 6 shows a summary of the self-ratings. For each of the six manipulation operations, we take the ratings for the 15 users and 3 body parts and perform a one-way ANOVA. For

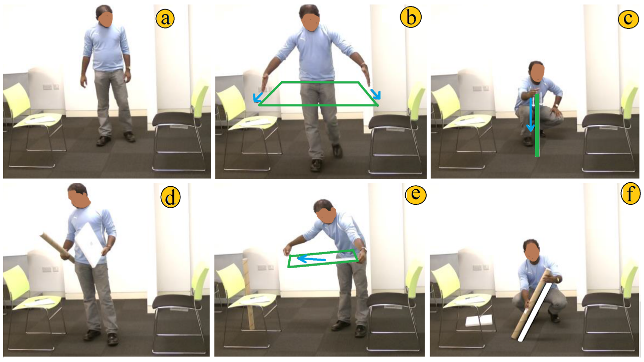

Figure 7: *Task 3 example images. (a) Space for In-situ dining table creation, (b-c) Gesturing with hands to express table top and legs. (d-f) Using the physical shapes for the same task. We have drawn lines and arrows on the figures to visualize the gestures and the users do not see this visual feedback.*

all six cases, the p-value is < 0.002 and hence the means of the self-ratings of the different body parts are significantly different. We then perform a Tukey's test for each case. For move (at waist height), scale up, and bend, comparing all three pairs of body parts gives p-values of < 0.05. For move (on floor), rotate, and cut, the p-value of legs/feet vs. hands/arms is > 0.05 while the p-values of the other two pairs are < 0.05. The overall result for Task 2 is that *gesturing with hands/arms is the most preferred and this is statistically significant* (and there are some cases where hands/arms and legs/feet are equally significant).

Task 3: Furniture Creation with Virtual/Physical Primitives. Figure 7 shows an example of a user creating a furniture item with various body parts and gestures and the first-person modeling concept. The result here is that participants are able to use all of the three different ways to create furniture items. The mean self-rating for "body movements/gestures only" is 3.8 (std 0.94), for "virtual shapes + gestures" is 4.0 (std 0.79), and "physical shapes + gestures" is 4.4 (std 0.64). However, when we take the ratings for the 15 users and 3 cases and perform a one-way ANOVA, the p-value is 0.124. Hence there is no significant difference between the means of the three groups. The overall result for Task 3 is that **all three cases are equally good** and work well for the users in describing various furniture items.

5. Discussion

We discuss the results of the user study and post study questionnaire in this section. We provide suggestions for designing first-person 3D modeling interfaces using human body parts and gestures.

Gestures and Postures. We observed that participants use a unique combination of gestures and postures for certain creation and manipulation tasks. For example, Figures 8(a-c) show that while making gestures with a specific body part, the other body parts maintain a unique posture. These postures can be characterized by the positions and orientations of the non-gesturing body parts. In addition, users sometimes made a similar set of movements/gestures in different orders for some shapes. Consider for example the description of a cone by two different users. One user starts by describing the base and then the top part, while the other user performs similar gestures but changes the order of parts.

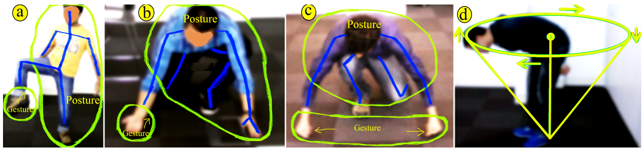

Figure 8: *Gestures and Postures. We have placed text and drawings on top of the images to explain our observations. (a-c) Participants using a unique combination of gestures (with feet or hand) and postures (with other body parts) to perform bending (a,b) and scaling (c) operations. (d) Participant takes a first-person metaphor where his legs become the central axis of the cone and his torso represents the radius.*

For creating shapes, participants use their body parts in two ways. They either make body movements to directly trace the shape of the object in free space (this is the usual case as mentioned in the results above), or they first assume a first-person metaphor where some part of the object is assigned to a body part (as in [ZHR*13]) and then make a movement. For example, to draw a cone, one user makes a gesture (Figure 8d) in which he uses his torso to represent the radius and his legs as the central axis of the cone.

Suggestion: Even if our results show that gesturing with hands/arms is preferred, the user's non-gesturing body parts and overall static posture are still significant. We should build interfaces that also consider the user's body posture to recognize the user intention.

Shapes and Complexity. We found that the three cases of "gestures only", "virtual shapes + gestures", and "physical shapes + gestures" are all preferred by users. However, there were individual users who strictly preferred one case above the others (for all three cases).

As the complexity of the object to be described increases, for example from a rectangular surface to a cube, the number of movements to describe them increases. We observe that providing a set of virtual or physical objects for such primitive shapes might be useful to the user to begin with, such that they do not have to create some commonly used primitive shapes from scratch.

Suggestion: Hence we suggest an interface that starts with empty 3D space and with both virtual and physical shapes as options, such that users can experiment with different options for themselves.

Size and Dimensions. While creating a dining table, one user was able to sit on a chair to determine the actual height of the virtual table to be created. Moreover, one participant made a scaling gesture in dimensions similar to those of the room corner. Five users reported that it is easier for them to visualize the actual dimensions and style of the object to be created by taking clues from the nearby objects. Users felt that describing shapes in the real-world environment allows them to imagine the context and relate the new object to the existing objects more easily. However, two users reported that nearby existing objects may cause hindrance while describing shapes as they occupy space.

Suggestion: Existing objects can be placed nearby such that they can be optionally used as part of the interface when needed and preferred by the user.

Multiple Designs. Some users were able to come up with multiple designs for a particular furniture item. For example, one user first described a rectangular primitive shape for the table top and a sphere cut in half for the base. Then he asked for permission to describe the object again and came up with a different design by using a cone and a circular surface.

Suggestion: Allow for flexibility in the interface for exploration and for multiple designs.

6. Conclusion, Limitations, and Future Work

We investigated the use of gestures with different body parts for first-person 3D modeling. We have found that employing different body parts for gesturing in 3D space is a complex task and there is still much to be learned.

One limitation of our work is that the participants received no visual feedback (in terms of visualizing the virtual shapes that they "draw" in space). They performed the gestures but did not see their effects, thus making it a one-way communication. Although we are able to elicit gestures effectively in our work, adding visual feedback and then eliciting gestures would be an interesting possibility for future work.

The lack of accuracy with body gestures is a concern and two users specifically reported this. Using the body as input will not work for modeling detailed shapes. In general, gesturing with human body parts is useful for prototyping coarse 3D shapes and would be complementary to CAD software for detailed 3D modeling.

It was very tiring for some users to make descriptions using body parts. Additionally, one user reported that the size of the object to be created is bounded by the expansion of his arms or legs. These are expected disadvantages of interfaces using human body parts. It is possible for users to move around and gesture in a larger scale. Interestingly our users did not move or walk around even though they were not limited to a fixed space. Exploring this possibility and encouraging users to dynamically move themselves is a potential direction for future work.

We have focused on eliciting the body parts and gestures that are preferred by users for a set of 3D shape creation and 3D manipulation operations. Future work includes implementing gesture recognition techniques and a corresponding 3D modeling system.

Acknowledgments

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