"Form Follows Function" – Investigating Interactive Physical Objects in Virtual Environments

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Abstract. Controlling the available degrees of freedom in virtual environments often represents a challenge for the design of 3D user interfaces. Based on the concept of Tangibles and their natural affordances for spatial interaction, we conducted a study to investigate how users intuitively use physical objects in Virtual Environments. The results reveal a wide range of different approaches. This specifically relates to the utilization of an object's surface or edges for different functions or as representation of elements in the virtual world. The findings of the study have several implications on further research directions regarding tangible objects in Virtual Environments.

Keywords: 3D User Interfaces, Tangible Interaction, Virtual Reality.

1 Introduction

Without constraining the interaction, the available degrees of freedom in three-dimensional virtual environments make it difficult to execute tasks efficiently and precisely. Within the last decades different technologies were developed and tested in this context, for example gesture or speech. The use of natural gestures and movements in virtual environments has several disadvantages, such as the lack of haptic feedback [1] and the restricted interaction space. A different approach incorporates the concept of Tangible User Interfaces (TUI) [2]. Apart from providing haptic feedback, physical objects offer intuitive affordances [3]. Previous research has shown that using Tangibles for interaction can increase the performance of specific tasks [4]. At the same time, carefully designed TUIs can enhance the comfort of interaction [5]. By consulting principles of interaction from the real world, the required mental effort for operations in the virtual environment can be reduced [6]. The gained benefit from applying real-world-principles can be improved by extending objects with additional digital capabilities to increase their power and versatility [6]. Therefore digital augmented physical objects provide a method to bridge the gap between real and virtual environments [7]. By carefully designing tangible interfaces their natural affordances can be utilized to guide the user and facilitate the interaction.

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2 Study Description

In order to evaluate how affordances of basic geometric objects are perceived and utilized, we conducted a Wizard-of-Oz experiment with novice users (cf**. Fig. 1**). Three different objects – a cube, a sphere, and a cylinder – in three different sizes were provided in random order to examine how the participants use them to solve particular orientation and navigation tasks.

During the experiment, the participants stood in front of a large screen, showing a realistic virtual environment. They were instructed to perform one of the following basic orientation and navigation tasks:

- "look 90 degrees to the right"
- "look up"
- "turn around"
- "walk three steps forward"
- "walk three steps to the right"
- "turn to the left and walk three steps in this direction"
- "walk backwards"
- "lift yourself approximately 3 meters upwards"
- "select the bridge near the tower"
- "teleport to the selected location"

The corresponding action in the virtual environment was presented as a scripted sequence, initiated by the experimenter. Afterwards the participants had to demonstrate how they would use the object to execute the default task. Therefore, the presentation of the intended outcome of the task and the task execution were separated steps, because the objects lacked built-in functionality.

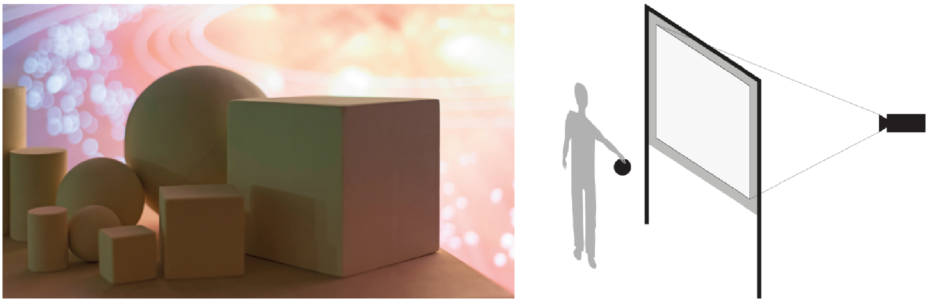

Fig. 1. Objects used in the study (left) and study setup (right): Participants use a tangible object to interact with a natural virtual environment projected onto a large screen

Between the blocks, which contained three sizes of one object, the participants had to rate the suitability and describe advantages and disadvantages of the different sizes of the object from their point of view. At the end of the study they were asked to evaluate the three different shapes in comparison and specify which object they preferred for the interaction scenario. The final questionnaire also included questions about desired additional technical capabilities and general comments on the study. 18 participants (10 male) between 19 and 42 years, averaging at about 26 years (SD: 4.99) took part in the study. Two thirds had previous experience with video games, mainly using PC for gaming (9 users), followed by Tablet or smartphones and consoles (6, respective 5 participants, due to the possibility to give multiple answers). However, all of them had experience using a PC and the vast majority stated being familiar with tablets or smartphones (16 participants, 89%).

3 Results

The quantitative results include a preference for sphere and cylinder. Rating the suitability for the given object between 0 (worst) and 10 (best), the sphere obtained an average rating of 7.44 (SD: 1.76), the cylinder was rated 7.22 in average (SD: 2.3) whereas the cube received generally worse ratings (mean: 4.53, SD: 2.44, Fig. 2).

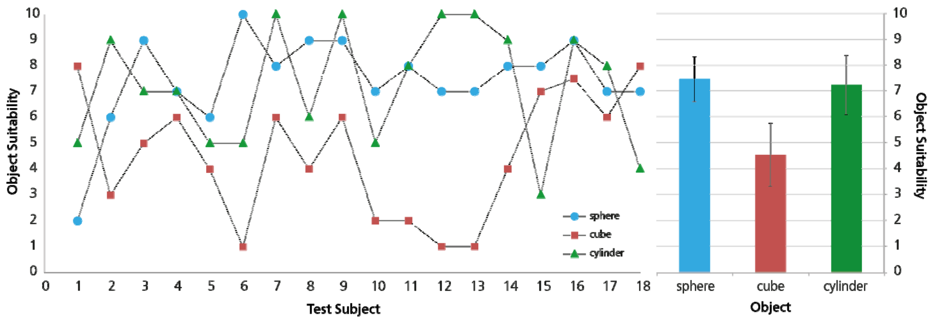

Fig. 2. Rating of object suitability

The object preference judgments show a similar picture. The sphere received an average rating of 7.33 (SD: 1.61), closely to the cylinder (mean: 7.17, SD: 2.38). Averaging at 4.78 (SD: 2.44), the cube did not receive a high rating regarding object preference (Fig. 3).

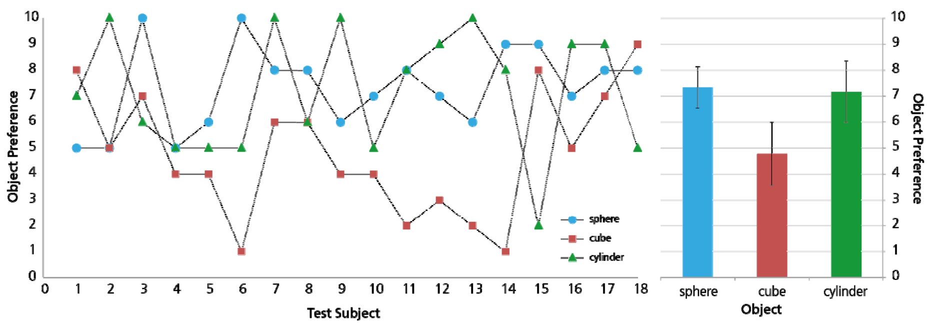

Fig. 3. Rating of object preference

These values are confirmed by the answers to the question which objects the participants could imagine to be using in a comparable setting. 13 participants voted for the sphere, 13 for the cylinder, whereas only 3 would use the cube in a similar scenario (multiple answers possible).

4 Observations

The observations of the participants during the study and the video-analysis of the experiment indicate a relation between object shape and interaction technique. Provided with a realistic scenario, some participants associated the object axes and surfaces of the cube with the spatial axes respectively with the spatial planes. The cylinder was commonly interpreted as a physical representation of the user in respect to the virtual environment. Therefore the participants used the cylinder similar to a pawn in a board game (Fig. 4). It was stated that the shape of the cylinder simplifies deriving a direction because of the natural given information about horizontality and verticality. Additionally some participants noted the straightforward distinction between lateral surface and top or bottom surface which facilitated the assignment and remembrance of different functions. The statements of the participants indicated that the familiarity of the shape due to its similarity to tools such as pointers, joysticks, pens or gear shifts facilitate the utilization.

Fig. 4. Relations between object shape and usage in an immersive scenario: The axes of the cube are projected on the spatial axes of the virtual environment, whereas the cylinder is perceived like a simple pawn

Regarding the cube, participants described the discrete surfaces as an advantage, which makes it easy to differentiate between functionalities associated with the different sides of the object. However, the equality of the surfaces leads to an ambiguity regarding the orientation which sometimes caused confusions. On the other hand, the cube offers a rich variety of possible interactions, regarding the use of vertices, edges and the surfaces. The participants often stated that, in contrast to the sphere, the cube wasn`t suitable to accomplish natural movements.

One frequent statement about the sphere refers to the positive haptic sensation it provides due to missing edges and the naturalness of the executed movements. The shape provides a flexible usage, as its shape does not infer a specific amount of applicable functions. The continuity of the surface allows continuous movements.

However, the sphere did not provide any clues about the current orientation, causing confusion among some participants. In contrast to the other objects, the shape of the sphere causes an inherent instability. Therefore many participants recommended a fixation of the object.

5 Discussion

On a general level, the observed interaction techniques can be divided into five basic forms:

1. *Walking* - The participants moved in front of the projection, holding the object in their hands. This implies that the shape of the object did not have any significant influence.
2. *Moving* - The object was moved relative to the body to execute an action.
3. *Steering* - The participants used small object-specific movements, such as tilting, rolling or sliding the object. The position of the object relative to the body or to the projection had no significant influence.
4. *Touching* - The surface of the object was used for interaction.

A common behaviour was a mixture of *Moving* for orientation and *Steering* for navigation. However, the observations imply a strong influence of the object shape, its size and the structure of the virtual environment on the type of interaction used: The specific interaction tasks are determined by the structure of the virtual environment (e.g. in an interactive visualization of the solar system an orbital navigation could be used, which incorporates completely different interaction tasks). On the other hand, the size of the object determines which interaction type may be used. Smaller objects are more likely to be used in conjunction of the first two types, whereas the surface is more frequently utilized when interacting with larger objects. The shape and its haptic sensation are another important factor, which explains why the cube was rated significantly worse regarding performance or suitability, despite of the numerous possibilities it offers.

The cube can be characterized as **static** and rather **abstract**. These characteristics stand in conflict with the immersive setting of the user in the study. In a more abstract or mathematical tasks, such as CAD or 3D-modelling, the cube may receive a higher rating. In contrast, the sphere can be described as **dynamic** and **organic**. However, this dynamism has some disadvantages. This could be addressed with a fixation, which may increase the stability and hence reduce the insecurity of the user regarding the orientation. The cylinder represents a combination of both types, as it incorporates both dynamic (when rolling) and static (standing on its ground surface) aspects. Its **anthropomorphic** form induces a congruency between the structure of the environment and the interaction device. Therefore, the cylinder represents a suitable instrument for operating in an immersive, real-world setting.

6 Future Work

The observations during the study reveal a large bandwidth of interaction techniques even with comparatively simple objects. Extending the capabilities of physical objects with additional sensors and actuators reveals potential for improvements regarding the range of functions provided. Additional sensors and simple changes to the original shapes could provide additional and unambiguous affordances for the user. Augmenting an object with digital contents seems a promising approach to fix disadvantages of the basic object shape. One example could be projected markers on a sphere which allows a dynamic orientation of the object.

Further research directions include exploring the user's mental models in virtual environments in context with Tangibles. As the structure of the presented environment has a strong influence on the use of the objects, comparing the use of primitive bodies in different scenarios could enhance the understanding of how users perceive objects and use affordances in a specific context.

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