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A multi modal table-top 3D modeling tool in augmented environments

Tom Novotny[1], Irma Lindt[2] and Wolfgang Broll[2]

[1]Media Cologne, Hürth, Germany
[2]Fraunhofer FIT, Sankt Augustin, Germany

Abstract

Even with today's highly sophisticated 3D modeling programs, creating, assembling and adapting 3D models is still a big challenge for inexperienced users. In this paper we present our approach of an intuitive table-top 3D modeling tool in Augmented Reality. It allows the author to view 3D virtual objects within his natural working environment, to manipulate them and to create new 3D elements easily. The offered interaction techniques support the author's activity by a combination of tangible user interfaces with voice recognition, a gaze-based view pointer and 3D widgets as components of a multi modal user interface. Within the scope of this work, intuitive interaction techniques were realized to offer the participants an easy way of working within an augmented environment. User tests were performed to compare our approach to a WIMP-based desktop application and to an alternative AR modeling application.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities H.5.2 [User Interfaces]: Evaluation/methodology, Graphical user interfaces (GUI), Input devices and strategies

1. Introduction

3D models are essential for many application areas including movies, games, architecture, interactive media, education, and industrial design. Typically, 3D models are created with off-the-shelf 3D modeling software. These software packages offer a wide range of functionality, but the usage is rather complex, though. Many toolbars, palettes, and filters make it difficult for non-expert users to quickly visualize ideas or to modify existing 3D models. The required functionality is often hidden in hierarchical menu structures and it is difficult for non-expert users to use the software without any guidance. Another issue is the spatial manipulation of the 3D models. Moving a 3D model in its coordinate system using a standard mouse and a keyboard is rather difficult, since it is often unclear how the 2D input values of the mouse are mapped to the 3D position values of the 3D model. Simple tasks such as positioning or rotating an object remain difficult to accomplish, might take very long and cannot be done intuitively by novice users.

Augmented Reality (AR) environments [Azu95] have the potential to offer more intuitive user interfaces for the manipulation of 3D models. Tangible User Interfaces (TUIs) [IU97], for example, allow users to grasp and manipulate 3D models by coupling them to physical placeholders. Typically, a placeholder is linked to a virtual object, thus the state of the real, physical object directly represents the state of the linked virtual object. TUIs are frequently used in AR environments to manipulate the position and orientation of a 3D model. In applications of 3D graphical design or modeling, the offered interaction metaphors block many natural abilities and force complexity on what might be done very simple. For non-spatial tasks, such as modifying the color or texture of a 3D model, further concepts for 3D user interfaces are required.

This paper presents a table-top AR environment for 3D modeling that combines TUIs with 3D widgets, a gaze-based view pointer and speech commands. The environment is not intended to replace existing desktop modelling software. Compared to desktop modelling software, the table-top AR environment offers only limited and rather basic functionality. Instead, we wanted to show that there are intuitive AR-based interaction techniques for 3D modelling allowing nonexperts for an intuitive and easy creation and manipulation of 3D models. The interaction techniques of the developed environment are compared to a table-top AR environment that employs alternative interaction techniques and to a standard modeling software for desktop PCs.

The paper is structured as follows: In section 2 we discuss related work regarding intuitive 3D interaction techniques with a focus on AR-based modeling systems. Section 3 introduces the set-up and the realization of our 3D modeling tool, and discusses and describes the individual interaction techniques. In section 4 the user test scenario and evaluation of the approach are presented. Section 5 discusses the results of the user tests. Section 6 concludes the paper and gives an outlook.

2. Related Work

Apart from off-the-shelf 3D modeling software such as Maya from Alias Systems (www.alias.com) or 3DS Max from Autodesk (www.autodesk.com), there are some modeling tools for desktop PCs that are more focused on specific application domains. Some of these 3D modeling tools can be found in the game industry. Nowadays, many games come with their own authoring tool allowing players to create game worlds without demanding great skills [CSFE04]. For the creation of VR environments, similar easy-to use tools exist. Virtools [VIR04] or EON Studio [ER04] are two examples of available commercial tools in the VR field. Another desktop-based tool for creating VR environments is Alice [CAB*00]. Alice is a rapid prototyping system for creating interactive computer graphics applications by describing the time-based and the interactive behavior of 3D models. It is designed for people with no 3D graphics or programming experience.

In the past few years a lot of effort was put into the development of AR systems to offer easy-to-learn interaction techniques for creating and manipulating 3D models in augmented environments. One example is the TUI in *mQube* [BGH*04]. It takes advantage of placeholder objects (PHO) to e.g. place and manipulate 3D models or to define specific paths that are linked to virtual characters. The generic user interface in *Tiles* [PDB*02] is based on visual markers (so called tiles) coupled to 3D content. The system contains two classes of tiles, data tiles and operation tiles, to hold arbitrary digital content and operations that are applied to data tiles.

The *BUILD-IT* application [RFK*98] is a prototype for collaborative planning and supports engineers in designing assembly lines and building plants. The participants use a table top interaction area with a supplementary projection of a 2D computer scene on the table. A computer vision (CV) tracking for PHOs enables the usage of physical objects as universal interaction handlers. For a 3D view of the virtual scene, an additional vertical projection screen is installed. In *Put That There* [Bol80], Bolt introduces an early example for combining speech and gesture to interact with the synthetic environment. AR technology is not only used for creating new architectural models, but is also employed to get an impression of already existing plans.

In the *TINMITH2* System [TPG00] 3D content from CAD applications is visualized in its physical outdoor context. Another example is the *Assembly Instructor* [ZHBH03] for easy content authoring and context-based visualization of hierarchical assembly tasks. Dias et al. presented *The Manipulating Magic Rings* [DSB01] for easy gesture-like manipulations, where objects should support spatial and two-handed manipulation by their form. This type of TUI combined with *The Magic Book Metaphor* is applied in *Mix It* [BKP01] and evaluated in [DJC*03].

AR systems for collaborative design sessions typically support the spatial composition of larger designs from existing building blocks. They provide planning rules, offer intuitive interaction mechanisms and have mature concepts for integrating physical and digital work spaces. In development phases of products and service solutions AR applications can improve and shorten the design process in different stages. Due to the lack of standardized 3D user interfaces many AR modeling tools fall back on graphical user interfaces that force the user to work at a desktop PC during the creation of 3D models. Many approaches are restricted regarding intuitive interaction mechanisms and functionality.

In [FSSK02] a TUI was compared with three alternative single-user tools (a 3D physical, a 2D cardboard, and a mathematical tool) through an empirical investigation. Participants had to solve the same positioning problem with each tool. The 3D physical tool significantly outperformed the 2D cardboard tool. It also outperformed the TUI, but only in user satisfaction. This motivates researching TUI systems and comparing them to other interaction possibilities.

3. Our Approach

The AR modeling tool was developed to support table-top 3D content and design sessions. The goal of this development was to provide an efficient mechanism to interact with an AR application intuitively, while preserving the communication with other persons involved in the design session. This section is subdivided into two sections. The initial scenario consisting of the system components with the setup is presented as well as the defined interaction mechanisms of the AR modeling tool.

3.1. Initial Scenario

The initial scenario is based on *ARTHUR - The Augmented Round Table for Architecture and Urban Planning* [BLO*04], an AR system for architects to support the individual phases of architectural constructions or city planning. It offers the necessary environment combining different technologies to allow collaborative sessions between experts without altering the established working procedures and well known tools. As part of this project dedicated hardware as well as several software applications have been developed to support architects and other experts in their everyday work. The approach uses the AR framework Morgan [OHL*04], AR displays, computer-based head and object tracking of PHOs, spatial pointers, gesture recognition, and hybrid tracking systems. The setup of this prototype is shown in Figure 1.

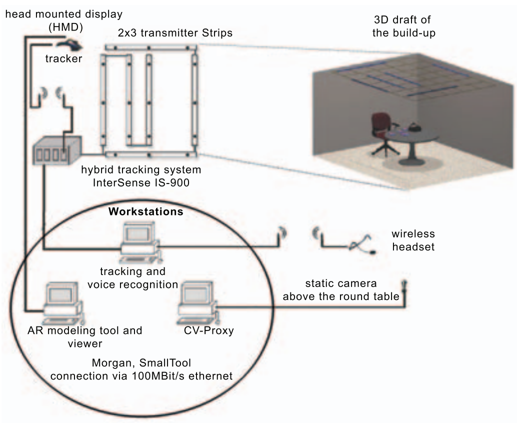


Figure 1: *Scenario and system setup*

3.2. Interaction mechanisms and modalities

Within the AR modeling tool advanced and intuitive user interaction techniques for manipulating 3D content are offered to the participant. The architectural desktop was used as metaphor and starting point for the design of the user interface, defining the characteristics of the interaction environment. One fundamental decision concerned the number of degrees-of-freedom (DOF) to be offered to the users for manipulating 3D content. On one hand the environment should be as intuitive as possible, not constraining the user's interaction, on the other hand, too complex operations may confuse or overextend especially those users inexperienced with 3D manipulations.

In our approach the *view pointer* - a gaze based interface - is used for 3D model selection. It is based on a crosshair projected in the center of the viewing field and allows for the intuitive selection of 3D content (similar to a standard 2D mouse) by moving the head accordingly. By that, an off-target pointing is excluded as often happens in 3D-selection mechanisms, as described in the following section. 3D content can only be selected, when it is in the user's region of interest (ROI) and is targeted via the view pointer. When a user focuses a virtual object a green bounding box provides visual feedback. By activating a manipulation tool using a voice command the bounding box of the focused object turns to red.

Our evaluation showed that color coded optical feedback supports the user in collaborative sessions to differ better whether an object is currently manipulated by another participant or not. There is little doubt that voice interaction will play a major role in the array of potential interface technologies, in the sense of combining it with visual feedback, use of a pointing device, gesturing, and other modalities [OO94].

When performing rather complex 3D manipulation tasks in a 3D and especially an AR environment, the user's hands or eyes are busy performing a specific task. In such a situation, using voice as an additional interaction modality to communicate with the computer, the participants are free to pay attention on their task, rather than breaking away by e.g. searching and pushing a button on the keyboard.

In our 3D content modeling scenarios, voice commands were used to activate a specific tool for manipulating a selected virtual object. For this reason, commands for loading a 3D model list, translating, rotating, scaling, color changing of a virtual object, or closing an active tool had to be defined. To attain a sufficient high level of recognition accuracy to bridge the ambient noise, the disruption of the microphone equipment or the user's physical and emotional state, 15 possible voice commands with 17 persons from different countries and with different accents were evaluated. To ensure that the system is usable even by participants, who are not familiar with the English language, the key words had to be simple, short and well chosen. The commercial voice recognition software IBM ViaVoice was chosen to allow the application of different vocabulary languages easily.

Though, the focus of our attempts was to specify English words as key commands. Beside the objective appraisal by the software, the participant's subjective estimation of the most suitable key words was also respected in the specification of the commands. The results of the evaluation of the key words finally used for the modification tools as well as other commands are listed in Table 1.

Confirmed by the participants' subjective impressions, the objective results show that short key words are preferable as they are much better recognized by the software. The subjective reasons for the missing acceptance of rather long key words such as "translation" or "appearance" were both a lack of correct English pronunciation and the fact that these commands were harder to remember by the test persons. As shown in Figure 2 a virtual voice command list containing the key words was displayed behind the real round table at eye level as an online reference for the users.

Some AR user interfaces utilize special purpose I/O devices, such as pointers or gloves. While these devices are often easy to integrate and intuitive in their usage, their use is rather limited to particular tasks. Geometrical interaction el-

Tool	*Key word*	*Cognition*	*Action*
PositionTool	move	96%	translational manipulation
RotationTool	rotate	92%	rotational manipulation
ScaleTool	scale	95%	scaling manipulation
ColorTool	color	98%	appearance manipulation
-	delete	98%	deleting a selected 3D model
-	close	98%	closing an active manipulation tool
-	show list	88%	activating the 3D content repository
-	hide list	92%	deactivating the 3D content repository

Table 1: *Key words for initializing the specific manipulation tools and additional interactions*

Figure 2: *The augmented voice-command list in the user's eye level and the activated 3D content repository*

ements with integrated functionality, such as 3D widgets are flexible and allow the representation of abstract and complex functionality. Major tasks for manipulating geometry include moving, rotating, scaling and changing the color of a 3D object. Although, nowadays desktop-based applications have a well-defined set of graphical user interface concepts to work with, no common user interface paradigms have yet been defined for immersive AR systems. Humans are used to touch an object for manipulating it, rather than using oblique devices. When interacting with familiar everyday items, we do not have to plan ahead to solve typical tasks. The approach of a TUI simplifies the interpretation of an interaction device and makes it easier for novices to solve e.g. geometrical problems than using conventional interaction utilities such as a keyboard or a mouse.

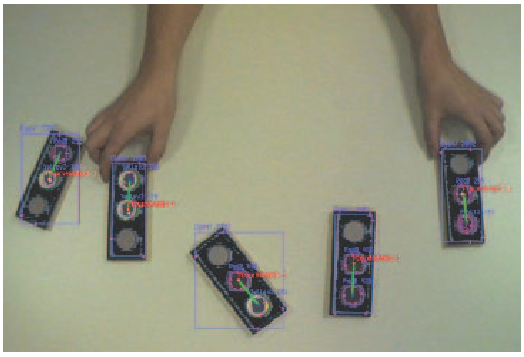


Figure 3: *Tangible Units*

To take advantage of this, small bricks of light weight and convenient size were chosen as primary interaction device for a fatigue-free way of working, as shown in Figure 11. Up to 15 color-coded PHO are detected by the CV system [MSL*04], using a small camera above the region of interest, mostly a round table, to extract the X-Z-Position on the table as well as the orientation over the Y-axis (see Figure 3). This way the table plane is observed to track two translational and one rotational degree of freedom. In design sessions 3D content, e.g. a part of a building, can be linked to a PHO by the participants, e.g. to translate the 3D model by a real brick. One of the used TUI elements is the *WorkingTangibleUnit* (WTU), the main interaction unit for manipulations. By moving the WTU translational on the table the X and Z-Position are used to move, rotate or scale the selected 3D model along the X and Z-Axis depending on the current tool selected. Planar rotations are mapped on the manipulations along the Y-Axis.

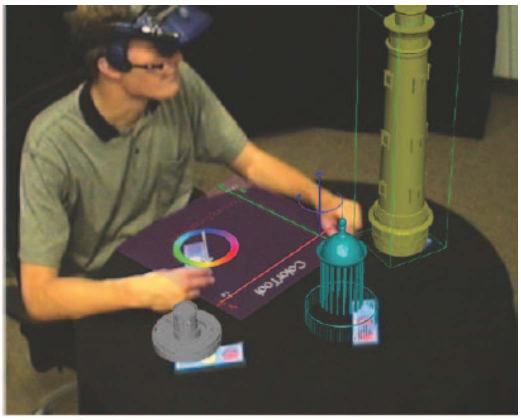


Figure 4: *TUs and 3D widgets as user interface elements*

For example, the *ColorTool*, as shown in Figure 4, maps the translational and one rotational DOF of the WTU to change the appearance (hue, saturation and value) of a selected 3D model easily. To fulfill the user's expectation and to ease the learning process of using and interpreting the offered tools, the appearance of all 3D widgets is designed in a consistent way for easy understanding. In order to support the users to interact from all locations around the table, the 3D widget of the currently activated tool is visualized at the current position of the WTU after its initialization (Figure 5). When moving around the augmented scene, the participants may take along their WTU to interact from a different position. For additional optical feedback of the manipulation values we use a head-up information bar in the right bottom position of the view to assure suitable control of the manipulation parameters, as shown in Figure 5.

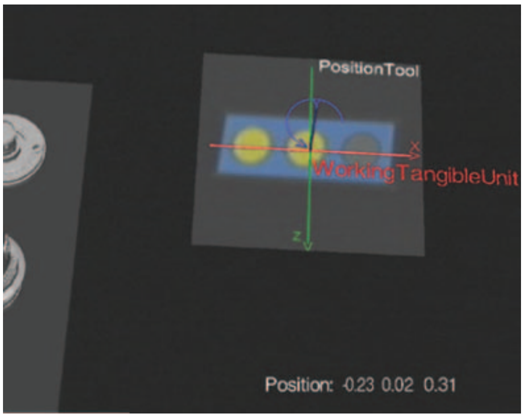


Figure 5: *3D Widget: PositionTool*

As already mentioned, a virtual model selected by the user's view pointer, is high-lighted by a green bounding box, acting as a visual feedback to the participants, whether the desired model is focused properly. By a voice command, e.g. "color", the picked 3D model's bounding box turns red to indicate that the corresponding 3D model is currently locked. At the same time, the *ColorTool* 3D widget appears at the WTU's tracked position. The user can either unlock the selected 3D model from the chosen tool by using the voice command "close", or apply another manipulation tool to the currently locked 3D model using another voice command or on one of the other virtual items on the table. Additionally, acoustic feedback supports the user with various sounds depending on the different interactions, such as selecting 3D models, initializing or closing an interaction tool.

3.3. Realization of Interaction Techniques

Setting up and experimenting with different interaction techniques may become quite cumbersome and time-consuming. In order to keep the overall implementation effort reasonable while being fully flexible regarding the user interfaces and input devices applied, all interaction techniques were realized using our interaction prototyping mechanisms. The mechanism is based on *Behaviors*, which allow us to model interaction techniques rather than programming them. Basically, Behaviors objects modeled from a set of individual components are attached to individual objects or parts of a 3D scene to realize a desired functionality. The individual components for instance allow for catching events (Trigger), quering information about scene graph or system objects (Query), observe particular objects or input devices (Sensor), or manipulate scene graph objects or system components by issuing appropriate events (Action). For a more detailed discussion of the individual Behavior components available please see [BLO*05]. Figure 6 provides a simplified example of the components used to model the Behavior realizing the selection and color changing interaction.

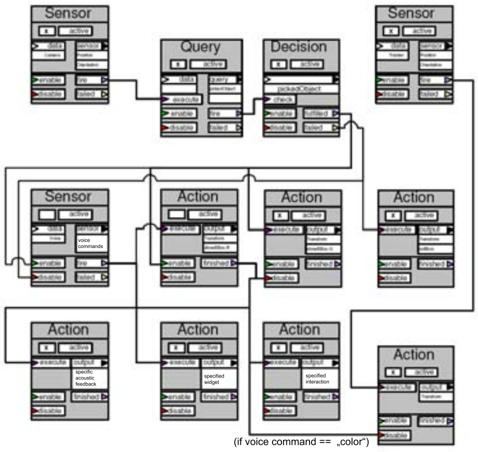


Figure 6: *Simplified diagram of Behavior components realizing a particular interaction technique*

4. Evaluation

For the evaluation of the AR user interface and its interaction techniques, 16 test persons were guided through five different stations. 10 of the test persons were male, and 6 were female, 50% of the users were experienced with AR or at least 3D in general, while 8 users were complete novices to the topic. For generation-overlapping evaluation two children at the age of 10 and 12 were also invited to the user tests.

The tasks of the test persons were to construct virtual buildings from existing 3D models and to adapt the appearance of the created 3D models according to given reference models. In order to compare our AR modeling tool with existing tools for 3D content creation, test participants were asked to perform the same tasks using our AR modeling tool, a standard desktop-based 3D modeling application, and an alternative AR based modeling environment. The main focus of the evaluation was on the intuitive use of the offered interaction mechanisms of each tool. The applied evaluation methods include quantitative as well as qualitative methods such as questionnaires, thinking aloud protocol and task performance measurements [DR99]. Evaluated criterions were, e.g.:

- time to fulfill a re-construction of a reference 3D model
- number of re-spoken voice commands, additional mouse clicks or pointer selections, when an immediate execution of the desired command or task did not succeed
- observation of the user's satisfaction, confusion, frustration or tiredness

At station 1 of the usability study, each participant had to judge on the intuitiveness of the overall approach. The test persons were offered a couple of wooden bricks on the table, they had to put on an HMD and a microphone, but did not get any further instructions. Within the HMD, the voice command list, the 3D model repository, and the WTU (see Figure 2) were visible. The primary aim was to find out how the participants react to the unfamiliar situation, whether they can figure out what could be done using the 3D content and the offered voice commands.

At stations 2-4, the participants had to solve two spatial manipulation tasks: within a desktop 3D modeling application (3DS Max) using mouse and keyboard as input devices, a *GRAIL*-based AR content creation application using a 5-DOF pointer, and our AR modeling tool using the 3-DOF WTU. The required time was measured for creating a virtual building (task 1) and a ball-bearing (task 2) according to a given reference model. The tasks included spatial manipulation, such as translating, rotating, and scaling of the 3D models as well as changing their appearances. Before starting each task the participants were provided with a short manual, explaining how to use the individual applications and where to find and activate the specific tools to manipulate the 3D content.

At station 5, the test persons had to answer a questionnaire to provide additional information about the interaction mechanisms. Additionally, different alternative representations of the visual components and tools were offered to the participants, as shown in Figure 7 and Figure 8. The users had to judge on the intuitiveness as well as the most pleasant / less disturbing representation.

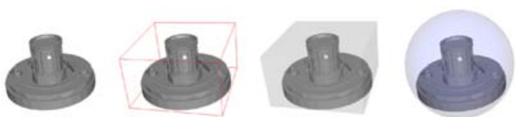


Figure 7: *Various visual feedback options for selected content*

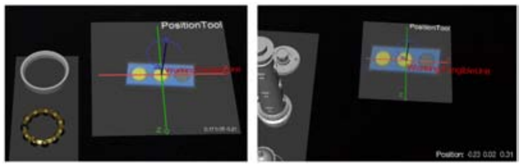
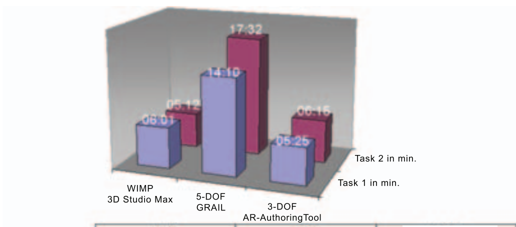


Figure 8: *Various 3D widgets with information feedback*

5. Results

The measurements for the amount of time required to perform the individual tasks illustrate impressively the major results of the evaluation (see Figure 9). The average time required for solving a particular tasks using the 5-DOF pointer is significantly larger than the average time required using our AR modeling tool or the desktop-based 3D modeling application. Solving task 1 as well as task 2 using the desktop-based 3D modeling application took approximately the same amount of time - between 5 and 6 minutes - as with the AR modeling tool. The 5-DOF approach took approximately three times more, about 15 to 16 minutes. A slight time improvement can be observed regarding the desktop-based 3D modeling application when comparing it to our AR modeling tool for the second task. This could be interpreted by a certain learning effect of the users. They learned the usage of the desktop-based 3D modeling application in the task before and were able to find the required menu items more quickly, as this seemed to be a major problem for novices using such applications.



	WIMP 3D Studio Max	5-DOF GRAIL	3-DOF AR-AuthoringTool
Task 1 in min.	06:01	14:10	05:25
Task 2 in min.	05:12	17:32	06:15
Time improvement	+14%	-24%	-14%

Figure 9: *Time-comparison between solving tasks 1 and task 2 within the different applications*

Many test persons complained about problems with the selection mechanism using the 5-DOF pointer. 3D models could not be selected as easily as with the mouse or the view pointer because of the difficulty in targeting a specified geometry. This is one reason why many test persons got confused and skeptical about the 5-DOF pointer during the AR session. In comparison, the WTU was judged as a very user friendly manipulation tool for 3D content. Comparing Figure 10 to Figure 11 reveals that the main difference in the usage of the manipulation method is the physical radius a user has to manage for wide range manipulations. Using the pointer, most test persons got fatigue very fast and several persons complained about arm aches during the test.

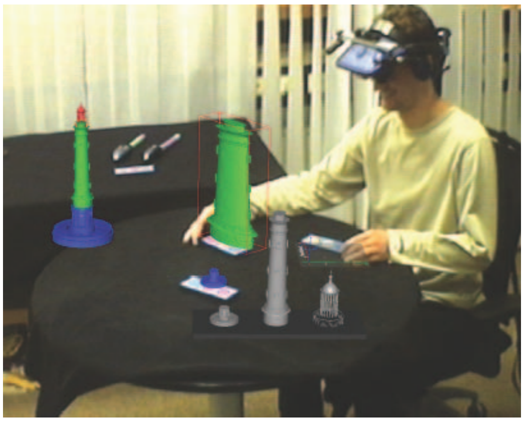


Figure 10: *Scaling interaction with the 3-DOF WTU*

Figure 11: *Scaling interaction with the 5-DOF pointer*

The selection methods used in our AR modeling tool support the user in collaborative sessions. 3D models that are selected once can be manipulated subsequently until the user deselects the models explicitly or initializes another tool for further manipulations. On the other hand, manipulations such as positioning were easier and more intuitive for the participants when using the 5-DOF pointer than using any other mechanism.

In spite of the limited degrees of freedom (3-DOF) provided by the WTU (compared to the 5-DOF pointer), the WTU was adopted very fast by the test persons and the interaction techniques used were judged suitable for AR table-top interaction. The users' expectations in the manipulation were fully fulfilled. Combining well-defined interaction techniques and different modalities, did not seem to overstrain the users. This was also highlighted by the fact that they used the variety of input techniques and the modalities offered spontaneously and intuitively. The time effort to learn the interaction techniques offered was very short as the use of 3D widgets was regarded as easy to understand. Thus, even AR novices were able to solve the tasks sufficiently with little temporal and cognitive effort. An extraction of the analysis from the usability study is shown in Table 2.

Quota of the test persons	*notices, statements, acceptance, aversions*
44%	understood the meaning of the VoiceCommandList immediately
69%	favored the scaling function of the WTU
81%	preferred the positioning function of the 5-DOF pointer
100%	stated that the RotationTool is very intuitive
86%	rated the ColorTool as easy to use with suitable visual feedback
100%	would prefer a color picker tool to define a specific color
94%	preferred the information about the selected 3D models in the field of view (,rather than on the 3D widget)
87%	insisted on the color coded bounding boxes and different sounds as audible feedback support
81%	stated that the interaction mechanisms are fast to learn and easy to use

Table 2: *Summary of some qualitative evaluation results.*

6. Conclusions

In this paper we presented a 3D modeling tool and described the interaction mechanisms realized within the context of the ARTHUR project. We further compared those to other AR and desktop-based interaction methods. The evaluation results revealed the advantages and disadvantages of our approach regarding the individual interaction devices and interaction techniques and modalities. In our future work we intend to modify our approach according to the feedback received. Especially the selection and feedback mechanisms require further improvements. We will further extend the environment to allow more complex 3D operations as common in other 3D modeling environments.

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