A Perspective on Interface Techniques in Tangible Augmented Reality for Mobile Devices

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Abstract

One option for interactions in Augmented Reality (AR) is using physical objects, called tangibles. When virtual information augments tangibles, users can interact with the tangibles to manipulate the virtual content. This work introduces six interface techniques with different shaped tangibles for handheld devices in Tangible AR (TAR). We explore challenges and opportunities for the TAR-based interfaces and give practical insight into implementing them. In a user study, we show that users prefer performing touch interactions with user interface (UI) elements on a touchscreen over UI elements that are virtually projected onto a surface. In the latter case, users are challenged with hand coordination. Which tangible type they prefer depends on the application: For applications that focus on 3D interactions, users in our study prefer realistically shaped tangibles. For applications where users focus on the AR device's screen, they preferred a generic tangible.

Keywords: tangible augmented reality, interface design, tangible interaction, app interaction

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1 Introduction

In Augmented Reality (AR), virtual information is augmented to a user's environment. One approach for intuitive interaction techniques is called tangible AR (TAR). Here, physical objects, called tangibles, are augmented with virtual content. Besides interacting with virtual application features, users can grasp and move the tangibles to manipulate the virtual content. For example, users can move and rotate a tangible to move and rotate the virtual content accordingly. Studies showed that users prefer interacting with physical objects over freehand interaction [DLB15].

This work explores how interactions can be applied to different tangible types and interfaces using handheld devices. We differentiate between tangible interactions and app interactions. Tangible interactions are interactions with a tangible, like moving or rotating it. This way, users can control which part of the augmentation they see. App interactions relate to interactions with virtual objects or user interface (UI) elements, for example, buttons for system functionalities.

We introduce a screen and a surface interface that can be combined with any tangible. For both, we describe app interactions and tangible interactions. For users with no experience in AR, it is not always obvious that they can interact with a tangible to manipulate virtual content. Therefore, this work targets to support users in realizing the connection between tangible and virtual content by using a realistically shaped tangible interface. Also, manipulation performance increases if the virtual objects look similar to the tangible that they augment [KKL09]. However, not all real objects are similarly suitable as tangible AR objects. For example, some physical objects might be too heavy or large to grasp. Furthermore, when holding a tangible in their hands, users have only one hand left for other interactions because the second hand is needed to hold the AR device. Depending on the tangible, interactions like holding, rotating, or moving it with a single hand can be difficult. Furthermore, using two hands at the same time for different movements requires coordination and practice. Therefore, this work also introduces a generic tangible interface that supports one-handed user interactions. Additionally, we combine interface approaches to create more affordances and open up new possibilities. An object has an affordance if one of its properties invites for a specific action [Gib77], e. g., a door handle invites to lever it or a button suggests pressing it.

In this paper, we explore how interfaces for tangible AR can be designed and how different interfaces can be combined by making the following contributions:

- We introduce six interfaces and combinations of interfaces for tangible AR in handheld device setups. (1) A touch screen interface, (2) a surface interface, (3) a use-case specific, realistically shaped tangible as interface, (4) a generic tangible as interface, (5) a combination of a realistically shaped and a generic tangible, where both serve as interaction devices independent from each other, and (6) another combination of these two tangibles, where both are combined to a single tangible. For each interface, we explore affordances as well as input and output possibilities.

- We point out approaches and challenges in creating and tracking tangibles that serve as interfaces in tangible AR. Additionally, we give practical insight into how these challenges can be handled.

- We show the feasibility of each interface by implementing a prototype of each and state lessons learned during the implementation process.

- Based on a user study, we draw conclusions on the interfaces' suitability for pattern-based applications. A pattern describes a general solution for reoccurring challenges [AIS77], for example, comparing two objects with each other. Based on the user study, we also analyze advantages and disadvantages of each of our interfaces and point out which interface suits which scenarios best.

2 Related Work

An established approach for tangible AR uses images as an anchor for virtual information. Today, tracking technology is not only capable of detecting and tracking images or markers, but also 3D information like known 3D objects. This allows to detect and track physical tangible objects that can then be augmented with virtual content and used as tangible user interface. Principles for such tangible user interfaces are described in work by Ullmer and Ishii [IU97] and the Tangible Media Group [MIT]. In follow-up work, the group presents an interaction model that describes the relation between a physical interface and its digital representation [UI00]. The authors describe one approach with design guidelines to create tangible user interfaces and another approach that re-purposes existing objects. One method to create personalized tangible user interfaces is described in work by Becker et al. [BKMS19]. Users can cut out shapes from plain paper and assign functions to the snippets. Then, the functions can be controlled by manipulating the paper snippets. However, their work does not target AR.

Billinghurst et al. draw from virtual and physical design principles to propose design guidelines for user friendly and intuitive AR interfaces [BGL05]. Furthermore, Billinghurst et al. [BKP08] introduce interfaces that combine tangible user interfaces with AR. Their goal is to apply the tangible user interfaces' intuitive manipulation to AR interface metaphors to support seamless interactions. A study by Datcu et al. [DLB15] finds that users prefer interacting with a physical object for pointing and navigating through a menu interface over free hand interaction. The authors use AR glasses to display the menu in front of the users to be able to compare interaction with physical objects to one and two handed interactions. However, for mobile AR with handheld devices, interactions are restricted to one hand because users usually hold the AR device with their second hand. Handheld setups are not considered in the study.

A framework proposed by Koleva [KBNR03] classifies the coherence between a physical tangible object and a linked digital object. If the physical object is a common object in the application domain and users perceive it as similar to its linked digital object, the coherence is high. In this work, a generic or general purpose tool has a low coherence. Hettiarachchi and Wigdor [HW16] propose a system that anchors virtual objects to real-world objects that look alike. For this, their system scans the user's environment to detect and select suitable real-world objects and then augment the selected real-world object with the corresponding virtual object. The authors state that this reduces the mismatch between visual and haptic feedback. Similarly, Kwon et al. [KKL09] found that a low disparity between physical and virtual objects can significantly improve manipulation performance. Henderson and Feiner [HF10] present a system that actively searches the user's environment to anchor virtual control elements to suitable physical objects. Their goal is to use affordances that are already present in the environment. For example, small holes, screws, dimples, or other raised geometry can serve as input or output devices and provide haptic feedback to users. However, Henderson and Feiner [HF10] focus on a domain-specific environment and do not cover affordances for common objects and environments like a table where users can place a tangible.

A tabletop setup is targeted in current work by Valkov et al. [VML19]. Their work presents a semi-passive tangible object that provides haptic feedback in form of programmable frictions for interactions with the tabletop setup. The tangible object can be applied to several use cases, for example, interactive workbenches or fish-tank virtual reality.

The above works show a variety of existing tangible interfaces in different setups, but none focuses on setups and tangibles for TAR on handheld devices. While mobile AR is already present in our everyday live environments, more research is needed to explore affordances and to design suitable interface techniques.

3 Mobile Tangible Augmented Reality Interfaces

In this section, we introduce six interfaces and apply each one to the three patterns *show and tell*, *compare*, and *sequence*. These universal patterns are transferred from the knowledge communication domain by Horst et al. [HD19] and applied to AR by Rau et al. [RHLD21].

Each pattern augments a tangible with a virtual 3D model. The *show and tell* pattern annotates the virtual 3D model with text boxes to inform the user about it. The text boxes are connected to the virtual 3D model with lines. The *compare* pattern compares points of interest on the virtual 3D model with other virtual 3D models or images. This can be realized with lines that connect the virtual 3D models or by highlighting the points for comparison on each. In the *sequence* pattern, a virtual 3D model is shown in different states. Alternatively, separate 3D models that represent one state each can be augmented to the tangible. With an interface, users can switch between states.

Each interface and use case includes app and tangible interactions. One limiting factor for all tangible interactions with common handheld devices is that users have only one hand available because their second hand is needed to hold the handheld AR device. Depending on the tangible, interactions like holding, rotating, or moving it with a single hand can be difficult. Furthermore, using two hands at the same time for different movements requires coordination and practice. In some cases, users may occlude feature-rich parts of the tangible with their hands, resulting in a problematic tracking loss. For example, to view an augmentation that is anchored to a tangible from its backside, users must uncomfortably rotate their hand. If they occlude the tangible while doing so, further movements can no longer be detected until the occlusion is gone. Overall, a tangible should be small enough to allow users to hold it in one hand but large enough that vision-based tracking technologies can detect and track it. At the same time, it should be lightweight to prevent users from fatigues holding the tangible.

3.1 Touch Screen Interface

Touching user interface (UI) elements on a touch screen is an established interaction on handheld devices. Interactions via gestures, e.g., swiping, are also possible but can only serve their purpose if users are familiar with them. We visualize our touch screen interface in Figure 1. It uses buttons as UI elements for system functionalities like closing the application or switching between different pattern implementations. We place these buttons close to the screen's edge. This does not only avoid UI elements occluding central parts of the augmentations but furthermore allows users to tap UI elements with the same hand that they use to hold their device. Still, it can be challenging to interact with the screen interface while holding the tangible. If users are unable to do so, they need to place the tangible on a surface or in a stand. Alternatively, they can put the AR device in a stand. These touch screen interactions are independent of the tangible, i.e., they can also be performed while the tangible is not visible to the AR device's camera. While any tangible may be used here, a tangible that users can hold comfortably with one hand can support them in simultaneously interacting with it and the screen interface.

In the *show and tell* pattern, the text boxes can serve as interactive UI elements (Figure 1a). When the user taps a text box on the touch screen, further details can be shown. As these text boxes are anchored to the tangible, users can only interact with them while the tangible is visible and tracked. For the *compare* use case, we divide the AR device's screen into two sides (Figure 1b). One side displays a comparison object while the other side is further used for the augmentations. In Figure 1, the right side is used to display a virtual comparison object. Another option is to anchor a comparison object in the real world instead of displaying it statically on one side of the screen. However, in this case, an anchor within the user's environment is necessary. If the tangible is used as an anchor for both, it is necessary to further define and elaborate on the effects of the tangible interactions. Although tangible interactions like translation should affect both tangible and comparison object, other decisions are use case dependent. Should, for example, rotating the tangible cause the comparison object to be rotated as well, or does it remain in a previously defined orientation? If the comparison points are to be viewed from the same angle, the first option should be applied. If the tangible is to be aligned with the comparison object the comparison object should not move with it. To navigate through the different states in the *sequence* use case, we display buttons at the bottom of the screen (Figure 1c).

3.2 Surface Interface

The surface interface utilizes a flat surface, e.g., a desk, to place UI elements on. This shifts app interaction to the flat surface. By this, the distance between tangible and other UI elements becomes smaller compared to UI elements placed on the AR device's touch screen. Therefore, the surface interface brings app interaction and tangible interaction space spatially closer together. We show a conceptual illustration in Figure 1.

To display UI elements on the surface, the surface must be detected and tracked. Furthermore, the UI elements are only visible as long as the surface is tracked. This allows users to display the UI elements only when required. To trigger events, users can cover UI elements by placing one finger above them. This is similar to interactions with real buttons. For example, users can switch between patterns by covering a button on the surface. Alternatively, UI elements can also be covered with the tangible instead of with a finger.

Besides UI elements, the surface can also be augmented with different highlighted areas. If the tangible is placed in a specific area, this can trigger an event, for example, switching to another pattern.

In contrast to the surface interface, app interactions are limited to the surface so that text labels in the *show and tell* pattern are not interactive. Therefore, the labels are not anchored to the screen but free-floating in the world space and anchored to the tangible. If the user rotates the tangible, the text labels are also rotated. Viewing further details can be triggered using UI elements or associated areas on the surface (Figure 1a). For the *compare* pattern, virtual objects that serve as comparison objects can be anchored to the surface (Figure 1b). This way, they are not influenced by tangible interactions. Navigating through different *sequence* states can be realized with the UI elements that are augmented onto the surface (Figure 1c).

3.3 Realistically Shaped Tangible Interface

This interface maps all interactions to a tangible, where the tangible's shape is similar to the shape of the virtual 3D object that augments it. By this, it merges tangible and app interaction spaces. For example, a 3D printed object can be augmented with its textured virtual object, and interactions can be mapped to the 3D print. With a realistic shape, tangible interactions become more intuitive because users can look at the tangible to see how they need to move and rotate the tangible to see a desired point of interest. Figure 1 shows vertebrae as tangible that can be augmented with a similar shaped virtual 3D object.

The tangible's material should be non-slippery and allow a firm grip without damaging the tangible. To ensure a good tracking quality, the tangible needs to be rich in features that can be detected with computer vision. If a tangible is created in a 3D printing process, one can support this by painting the tangible or gluing a texture that was printed on paper to it.

This interface allows triggering events directly through the tangible. One option here is to couple tangible interactions with app interactions. For example, moving the tangible quickly from the right to the left side could switch to the next pattern, similar to swiping on a touchscreen. However, if it is not clear to users

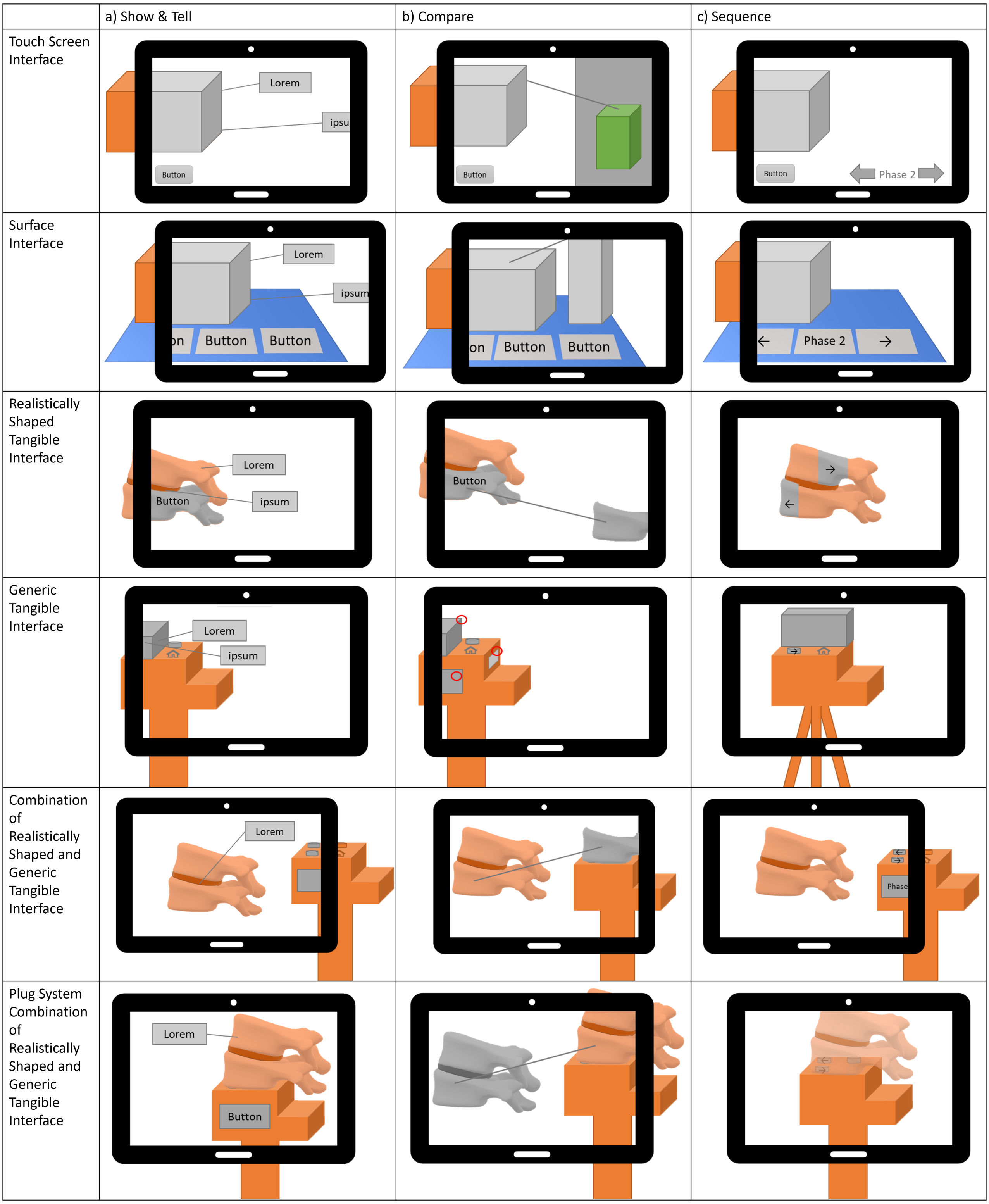

Figure 1: Conceptual illustration of our six interfaces for AR experiences based on the patterns a) show & tell, b) compare, and c) sequence. The orange-colored tangibles are augmented with grey-colored virtual 3D objects. For the compare pattern (b), we visualize the virtual comparison object green at the touch screen interface and include red indicators to compare specrific points of interest at the generic tangible interface. For the sequence pattern (c) with the plug system combination interface, we visualize the realistically shaped tangible transparent to show how it connects to the generic tangible.

how tangible interactions are mapped to app interactions, users might be unable to trigger events or might trigger events by mistake. Also, this approach makes interacting with subparts difficult. Another option is to place UI elements on the tangible itself or to use parts of the tangible as UI elements.

Within a *show and tell* pattern, additional information about a point of interest can be displayed when a user touches the corresponding subpart on the tangible (Figure 1a). For the *compare* pattern, a comparison between subparts of the augmentation can be started by touching the part on the tangible (Figure 1b). To switch between states for the *sequence* pattern, the tangible can be augmented with virtual buttons (Figure 1c).Some tangibles have a flat side that can be used to place them on a desk but is also convenient to place general UI elements on. On the bottom side, these buttons do not occlude important aspects of the tangible and can be used to switch between states or to trigger other system functionalities.

3.4 Generic Tangible Interface

In contrast to a realistically shaped tangible, a generic tangible has a shape that fits versatile use cases. It can serve as an interface for app interactions and tangible interactions. Similar to the realistically shaped tangible interface, it merges app interaction space and tangible interaction space. Ideally, the tangible's shape offers several affordances for multiple interactions and supports users in their interactions.

Our idea is to attach a handle to the generic tangible to make it easier to grasp and to facilitate tangible interactions. The handle allows rotating the tangible easily in all directions without occlusion through the user's hand. Therefore, it facilitates viewing virtual 3D content that is anchored to the tangible from all sides. The handle simultaneously works as a tripod. This allows users to place and rest the tangible on a surface, for example, on a desk. Then, users can hold their handheld AR device with both hands or use a single hand for tangible interactions. Figure 1 illustrates the generic tangible with handle for the show and tell and compare pattern, and with the handle functioning as a tripod for the sequence pattern. Another idea is to add bulges to the generic tangle. The bulges can be utilized as buttons, for example, to switch between patterns. They can have various shapes to give a hint about their functionality. For example, a generic tangible can have three universal round bulges and a fourth bulge that has the form of a house, as shown in Figure 1. The house is commonly known as a standard symbol for a home men,u and the bulge can be assigned with the functionality to switch to the AR application's home menu.

Additionally, a generic tangible can have sides with different aspect ratios. Our idea here is that virtual 2D content can be shown on a side of the tangible that suits the virtual content's aspect ratio (see Figure 1). The sides' different lengths also allow placing virtual 3D content so that it is partially occluded. This aims to increase immersion and to support users in more clearly identifying where the virtual object is located in relation to the tangible.

Similar to a realistically shaped tangible, app interactions can be triggered directly through the generic tangible. For this, the tangible interactions can either be mapped to trigger events or UI elements can be placed on the tangible as virtual buttons.

In the *show and tell* pattern, physical buttons on the tangible can be used to show or hide the text labels or further information (Figure 1a). For the *compare* patterns, the tangible's sides with different aspect ratios can be used to display comparison images while a virtual 3D object is augmented on top of the tangible (Figure 1b). The tangible's physical buttons can also be used to switch between states (Figure 1c).

3.5 Combination of Realistically Shaped and Generic Tangible Interface

Another interface combines a realistically shaped and a generic tangible to use the advantages of both. This places the app and tangible interaction space close together but keeps them independent from each other. In this interface, tangible interactions should be mapped to the realistically shaped tangible and app interactions to the generic tangible. We visualize the combination interface in Figure 1.

This interface is not limited to a single generic tangible. It is possible to utilize different generic tangibles for different app interactions. This can be helpful if two or more generic tangibles provide different affordances that support users with the app interactions.

Placing the generic tangible in a specific position or orientation can trigger app interactions. Furthermore, the generic tangible's haptic buttons can be augmented with virtual buttons. It can also be extended with sensors, e.g., gyroscope and accelerometer as described by Dring et al. [DHRD21]. Then, app interactions are also possible without the need to put the generic tangible into the AR device's camera frustum.

In a *show and tell* pattern, the realistically shaped tangible is augmented with its virtual overlay and text boxes (Figure 1a). Using the buttons on the generic tangible, users can perform app interactions like hiding text labels or showing further information. In the *compare* pattern, the two tangibles allow comparing two augmentations with each other while keeping their tangible interactions independent from each other (Figure 1b). A virtual 3D object can be augmented to the realistically shaped tangible, while virtual objects of any shape or other information can be augmented to the generic tangible. For example, a virtual 3D model of vertebrae can be augmented to a tangible that is shaped like vertebrae, while further information can be augmented to the generic tangible. For a *sequence*, the generic tangible can be used to navigate through states (Figure 1c).

3.6 Plug System Combination of Realistically Shaped and Generic Tangible Interface

A realistically shaped and generic tangible can also be combined to form a single app and interaction space. Our proposed generic tangible has three bulges on its top that can serve as buttons but can also be utilized for a plug connection system as shown in Figure 1c. The realistically shaped tangible needs to be modified with space that fits the bulges to plug it onto the generic tangible. Plugging both tangibles together is similar to common plug connections and offers an affordance.

Our idea is that the generic tangible is detected and tracked while the realistically shaped tangible on top of it is augmented. To ensure stable tracking, the computer vision algorithms need to detect the tangible in every or most camera frames. If a realistically shaped tangible has a shape and material that makes it difficult or impossible to track stable, the generic tangible can be tracked instead.

With the plug connection system, we also utilize the tangibles to start applications intuitively with a plug and play metaphor. An application can prompt the user to plug the realistically shaped tangible on top of the generic tangible. Once it is plugged on the generic tangible, the application can start its part with the realistically shaped tangible. To navigate back, the user takes the realistically shaped tangible off. This reveals the home button on the generic tangible, and the application goes back to its home menu. When more realistically shaped tangibles are available, users can switch to another part of the application by plugging another tangible on top of the generic tangible. This transfers the app interactions to the plug connection.

Similar to the combined interface without plug connection, for a *show and tell* pattern, the realistically shaped tangible is augmented with its virtual overlay and the generic tangible with UI elements for app interactions (Figure 1a). The *compare* pattern can be realized similar to the realistically shaped tangible interface, where a virtual comparison object is displayed close to the tangible, or similar to the generic tangible interface, where comparison objects are placed on the generic tangible (Figure 1b). For a *sequence*, the generic tangible's buttons or virtual UI elements on the generic tangible can be used to navigate through states (Figure 1c).

4 Implementation

We apply our interfaces to the domain of continuing medical education. Here, we create one prototype that educates about the human skin and another prototype that educates about vertebras in the human spine. For the screen, surface, and realistically shaped tangible interface, we implement each of the three patterns *show and tell*, *compare*, and *sequence*. For the generic tangible and both combination interfaces, we implement the *show and tell* as well as the *sequence* pattern. We implement our applications using the Game Engine Unity [Uni] (version 2019.2.6, free personal license) and Vuforia [PTC] (version 8.5.9, free developer license for non-commercial use) to track our tangibles.

The screen interface places Unity UI elements like buttons on the touchscreen. The tangible is implemented as a Unity GameObject and placed in the real-world space. Figure 2 (left) shows a screenshot of a prototype with the screen interface and a *show and tell* pattern active. The Unity line renderer does not support drawing lines from the screen (UI) space directly to the real-world 3D space. Therefore, we anchor empty Unity GameObjects to the points of interest on the tangible and draw lines between them and the text labels on the screen. We apply this technique to the *show and tell* pattern as well as to the *compare* pattern. Additionally, we implement comparisons with a red circle that highlights the point of interest to *compare*. Unity UI elements are also used to navigate through different states in the *sequence* pattern.

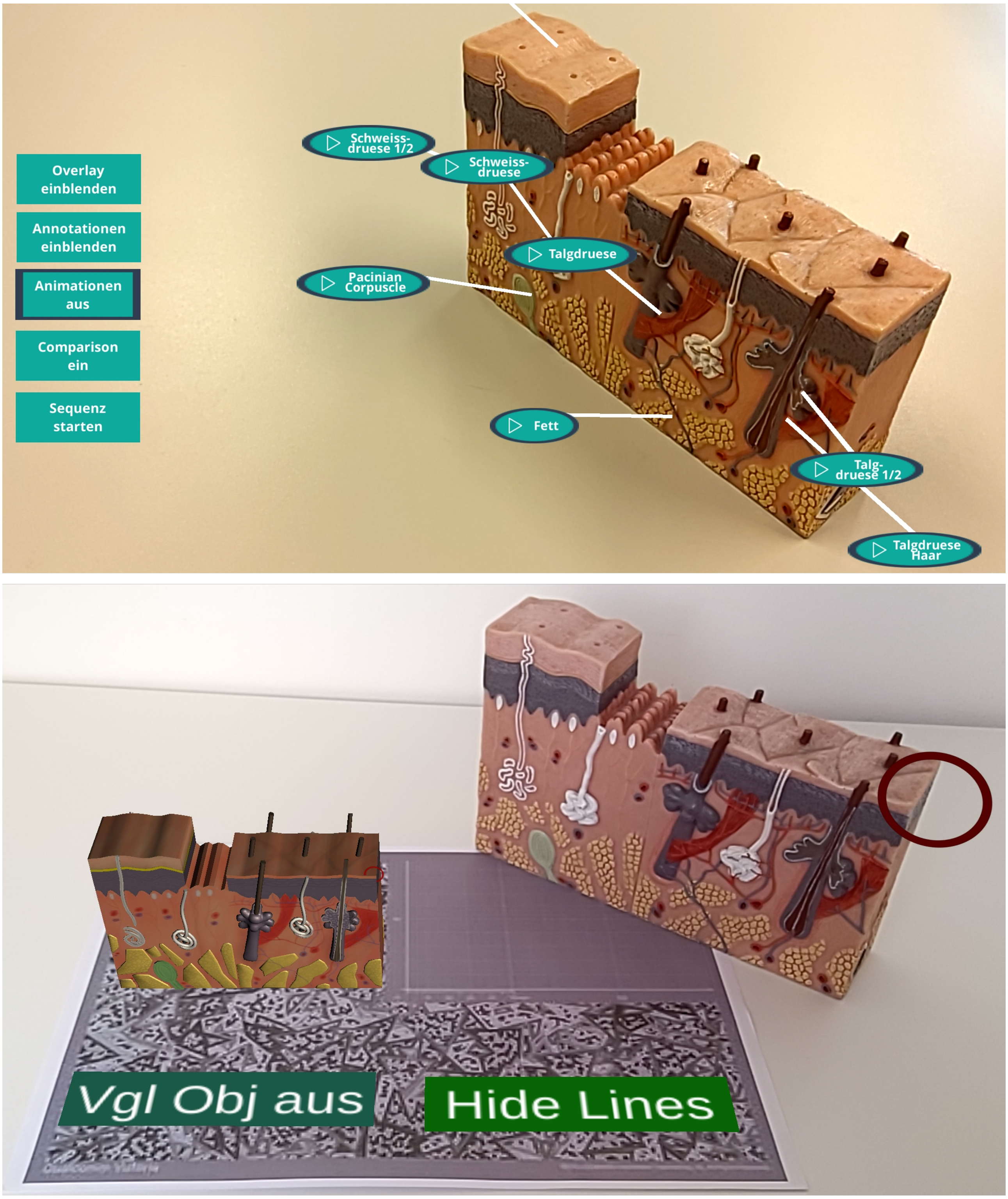

Figure 2: Screenshots of our prototype implementation. Top: The screen interface with a *show and tell* pattern active. A physical cross-section model of skin is used as realistically shaped tangible and augmented with interactive virtual labels. Bottom: The surface interface with a *compare* pattern active. A tangible skin model is used as a realistically shaped tangible. A virtual comparison object augments the surface. Two red circles highlight points of interest for comparison.

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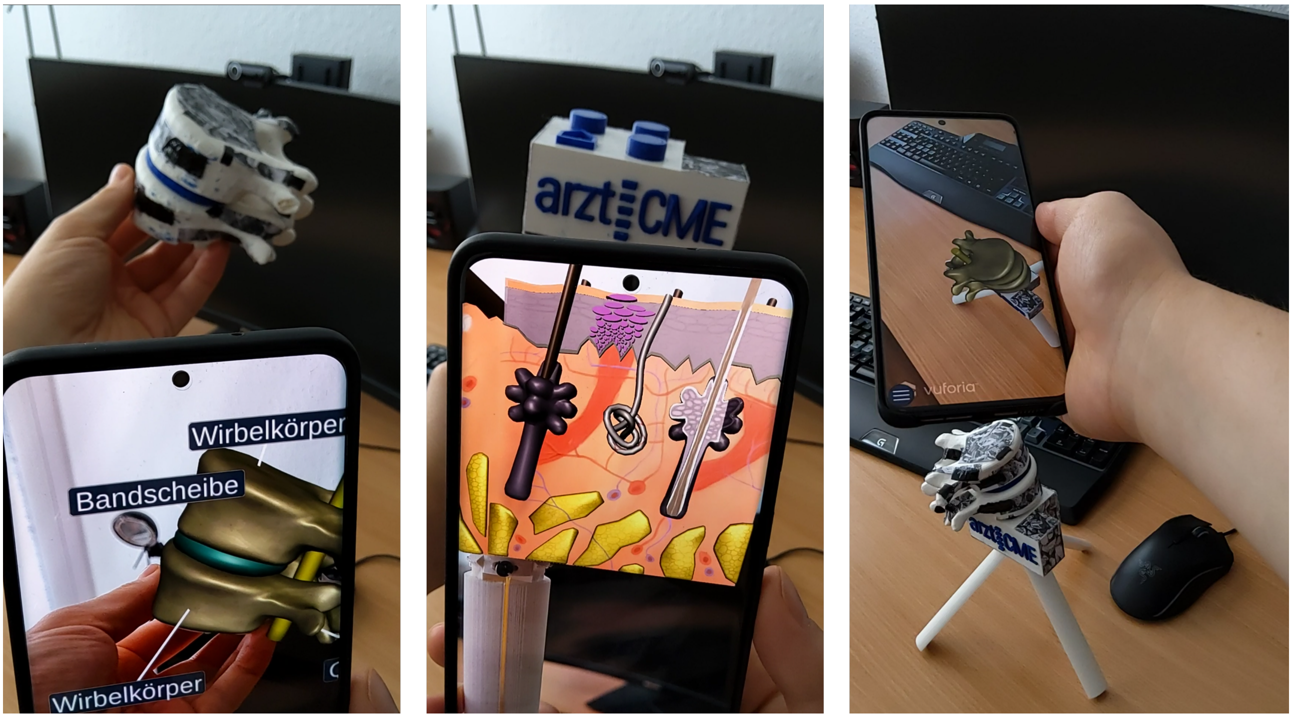

Figure 3: Prototype with the realistically shaped tangible interface (left), the generic tangible interface (middle), and the plug connection system interface (right).

The tracking toolkit Vuforia [PTC] supports tracking images and to utilize them as virtual buttons. We print an image and place it on our surface to use as an image target. The virtual buttons are augmented onto the image. When a user covers a virtual button, e.g., using a finger, the corresponding features on the tracked images can no longer be detected. This triggers the app interactions that are assigned to the virtual button. This arrangement is suitable with a small number of buttons but can be challenging when the number of buttons increases while the space on one image target remains the same. For example, when using many text boxes in a *show and tell* pattern, there might not be enough space on one image target to place a virtual button for each text box. For the *compare* pattern, we use the augmentations on the image target to indicate a place where a user can rest the tangible. Next to it, a virtual object can be displayed for comparison. A photo of our prototype with the surface interface and the *compare* pattern is shown in Figure 2. To navigate between states, we augment an image target with virtual navigation buttons.

For the skin prototype, we use a simplified cross-section model of human skin. As a reference for the tracking algorithm, we create an object target by scanning the skin model. For the vertebras prototype, we create and 3D print a model of two vertebras with a spinal disk as a part of a human spine. Initially, this 3D printed object is hardly trackable with Vuforia [PTC]. Its shape and colors do not provide enough information for stable tracking. Therefore, we apply a texture to the vertebras model. We print the texture on paper that we glue on the tangible. To the virtual model, we apply the same texture using UV mapping. Both realistically shaped tangibles are visible in Figure 2.

While virtual buttons can be augmented to an image, Vuforia [PTC] does not directly support adding them to a 3D object. Therefore, we include photos of our tangible as image targets. The virtual image targets are mapped to each of the tangible's sides. Then, we place virtual buttons on the image targets. Vuforia tracks both, image targets and tangible, to allow tangible interaction and app interaction simultaneously. The buttons can be used to switch between patterns and for app interactions in each of our three patterns. The skin cross-section tangible has one flat side that has too few features for stable tracking. Therefore, we place additional markers on that side and include them in the image target. This allows placing UI elements in form of virtual buttons on the tangible's flat side.

As generic tangible, we 3D print a model of the tangible that we described in section 3.4. Here, we also apply a texture to ensure a stable tracking quality.

To combine generic and realistically shaped tangible without plugging them together, both should be trackable robustly. For our 3D printed vertebrae model, the tracking quality was not stable so we focused on the combination with the plug system.

For the interface that combines generic and realistically shaped tangible, the first step is to detect the generic tangible. If no other tangible is plugged on top of it, the application instructs the user to plug the vertebras tangible on top of it. We use an animation that is shown in Figure 3 to guide the user to plug the tangibles together. When the vertebras tangible is detected on top of the generic tangible, the application augments the vertebras tangible with the corresponding virtual vertebras model. Then, buttons on the generic tangible can be used to switch between patterns for the realistically shaped tangible. When the user plugs the vertebras tangible on top of the generic tangible, the vertebras *show and tell* pattern starts. The user can switch to the *compare* or *sequence* part about vertebras using virtual buttons that are augmented to the generic tangible. To switch to another tangible, e.g., skin, the user takes the vertebras tangible of and plugs the skin tangible on top of the generic tangible.

5 Evaluation

The screen and surface interfaces can be used and evaluated with any tangible because app interactions are not mapped to the tangible. These two interfaces are rich on visual features that can be detected and tracked, so stable tracking is ensured. For the other interfaces, the tracking performance might have influenced the user study's outcomes. Therefore, we did not include them in this user study but plan to do so in future work. To evaluate the usability, advantages, and disadvantages of these two interfaces, we conducted a user study with 12 unpaid, voluntary participants (6 females, Ø 26.09 years old, SD 2.25 years). The user study employed the skin model as tangible and a Samsung Galaxy Tab S5e as a mobile device.

With a result of Ø 1.54 and SD 1.91, our participants classified themselves as laypersons in the field of AR on a 7-point scale (0: no experience; 6: regular usage). Firstly, we introduced our participants to the goal of our study and our implementation. During the study, each participant used the screen and the surface interface in random order to complete the following five tasks: (T1) Find the skin model with the tablet (warm-up). (T2) Discover different phases of the object using the *sequence* (chronological *sequence*). (T3) Display labels for the individual skin elements (*show and tell*). (T4) Display an animation of an object part (*show and tell*). (T5) Compare the model to a virtual version of it and display the corresponding features (*compare*). In the domain of continuing medical education, these tasks can support medical staff in learning about different stages or the course of a disease (T2 and T4), anatomy (T3), or differences between healthy and diseased organs (T5).

Finally, our participants filled out a questionnaire consisting of five questions (Q1-Q5) that each evaluated one particular aspect (A1-A5): (Q1) How do you rate the simultaneous use of the mobile, the tangible, and image targets (A1: coordination)? (Q2) Does the handling of the interface distract from the accomplishment of the task (A2: distraction)? (Q3) Does the interface leave enough free space to explore the tangible (A3: freedom)? (Q4) What challenges have you encountered while using it (A4: challenges)? (Q5) What other use cases could you imagine for this interface (A5: fields of application)? The questions Q1-Q3 were answered using a 7-point semantic differential scale (0: indicates a negative notion; 6: a positive one). Q4 and Q5 were answered on free text forms. Q1 and Q2 aim to inspect how challenging users find it is to coordinate holding a handheld device and simultaneously interacting with a tangible, an image target, or the mobile device. With Q3, we explore if an interface cuts back on the advantages of a tangible. Q4 allows users to point to challenges that were not specifically addressed with Q1 - Q3. Answers to the last question, Q5, can indicate ideas for future work and compare if one interface has a greater field of application than another. Thereafter, we asked our participants to rate how they liked each interface, considering the three distinct use cases on a 3-point semantic differential scale (-1, 0, 1). Finally, our questionnaire concluded with the items of the abbreviated AttrakDiff questionnaire [HBK03] to draw conclusions about the product character of our interaction metaphor, measured by means of hedonic and pragmatic qualities.

Our analysis shows that our participants favored the screen interface over the surface interface, considering A1-A3 (Fig. 4). Particularly, they assessed the coordination while interacting with the surface interface challenging. For example, we noticed that they

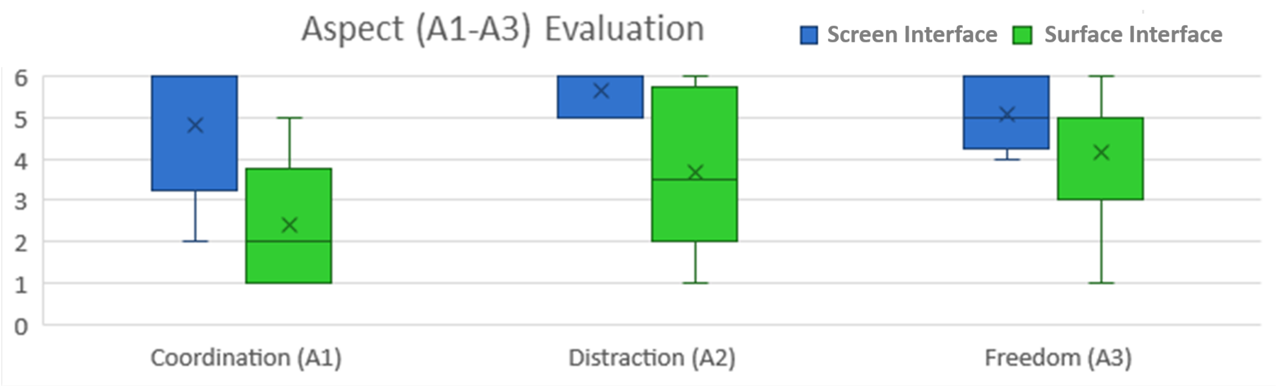

Figure 4: Box plots comparing the scores of our screen (green) with our surface interface (blue) relating to the three aspects A1-A3.

mistakenly touched buttons when performing tangible interactions or while trying to reach a button behind another one.

We compared the proposed interfaces with non-parametric and dependent Wilcoxon signed-rank tests [Wil50] for each aspect 1-3. With a threshold for statistical significance of 5%, two tests showed significant differences - both in favor of the screen interface. The differences occurred at A1 (coordination) with $p = 0.00424$ and A2 (distraction) with $p = 0.01078$. For A3 (freedom), the test did not confirm a significant difference ($p = 0.08364$). The analysis of the qualitative data for A4 (challenges) supports the claim that the participants found it difficult to coordinate their hands while using the surface interface. However, our participants also noted minor issues concerning the coordination with the screen interface.

We also could observe that some participants tried to interact with the mobile device with the hand that actually held it so that they did not have to switch their free hand between app and tangible interactions within the screen interface. We noticed that this worked well in most cases. After all, we could not observe that the screen or surface interface was better suited for a particular pattern. Finally, our participants indicate that for A5, they would use our applications mainly in museums or other educational fields.

The portfolio presentation of the AttrakDiff questionnaire [HBK03] compares our interfaces regarding hedonic and pragmatic qualities. The valuation of the AttrakDiff questionnaire [HBK03] (Fig. 5) shows that the screen interface is placed in 'desired', i.e., its hedonic and pragmatic qualities were rated positively. The screen interface's pragmatic quality was rated slightly higher than its hedonic qualities, which is shown with a slight shift towards 'task-oriented' in Figure 5. The surface interface was attributed with higher hedonic than pragmatic qualities and placed within the 'self-oriented' area. The differences in hedonic and pragmatic qualities between surface and screen interface are further visualized in Figure 6. It shows that scores were similar at three items ('unpredictable-predictable', 'tacky-stylish', and 'dull-captivating') and only one item had a higher score for the surface interface ('unimaginative-creative').

Concerning the application of the interfaces for certain patterns, our participants indicated on a 3-point scale (-1,0,1) that they found the screen interface most suitable for the chronological *sequence* (Ø 1.0), second most for *compare* with Ø 0.58, and then *show and tell* with Ø 0.06. They assessed the surface interface with Ø -0.25 for *show and tell*, Ø 0 for *compare*, and Ø 0 for chronological *sequence*. This illustrates that our participants liked the pattern implementations with the screen interface, specifically chronological *sequence* with a unanimously positive rating. The surface interface was rated mostly neutral, whereas *show and tell* was rated even negatively in mean.

Besides evaluating the screen and surface interface, we evaluated our tangible types by asking users to try applications using a Samsung Galaxy S20+ as a mobile device and the realistically shaped tangible, generic tangible, and combination with plug system interfaces. We use a *show and tell* and a *sequence* application for each of the three interfaces and apply them to two use cases: a vertebras model that educates about the vertebra structure and disk herniation as well as a skin model that educates about its structure and a

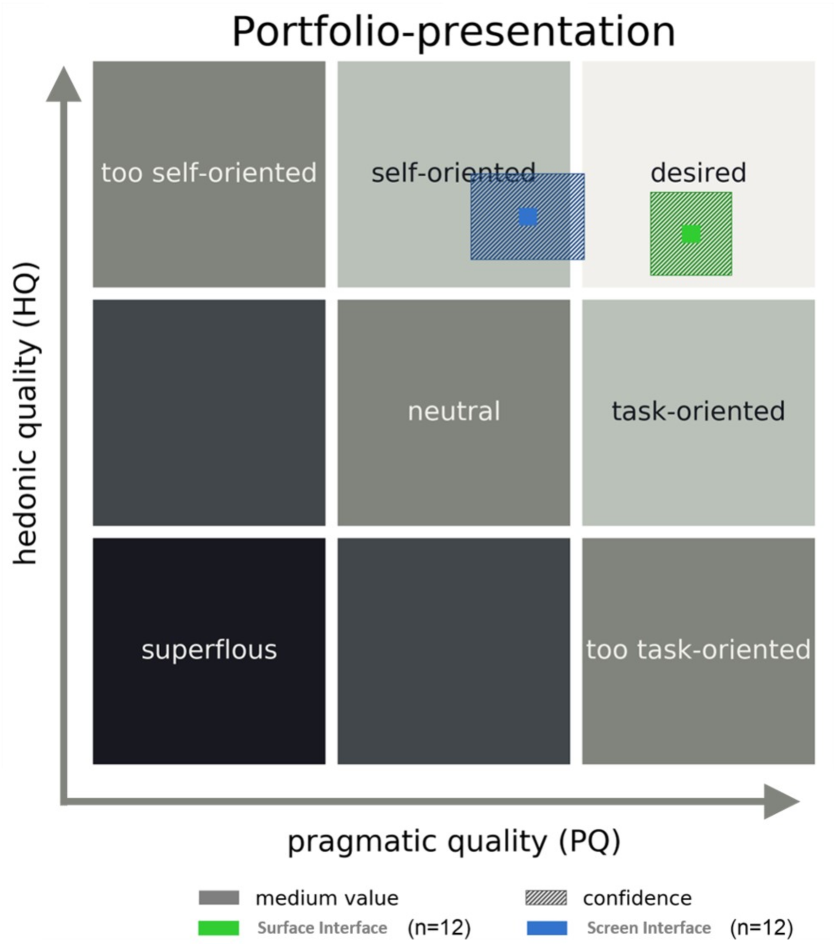

Figure 5: Portfolio presentation analysis [HBK03] (screen interface in green and surface interface in blue).

disease called actinic keratosis.

When we asked participants whether they prefer the realistically shaped or the generic tangible, they stated that it depends on the pattern in the application. In the show and tell pattern, it is important that users view the virtual object from all sides to understand the virtual object's structure. Here, the tangible's realistic shape and haptic feedback supports users in moving and orientating the tangible as desired so that they can focus more on the text labels. For the *sequence* pattern, the focus was rather on the sequence that was displayed on the AR device's screen than on any 3D components. Here, users prefer the generic tangible for the *sequence* pattern because it is possible to rest it on a surface and the tangible's shape is of secondary importance. In contrast to placing a realistically shaped tangible on a surface, the generic tangible can be placed on its tripod without laying directly on the surface. This way, the virtual content anchored to the generic tangible can still be viewed from all sides, including from the bottom. This illustrates that a handle with tripod functionality is supportive for one-handed moving and rotating interactions in handheld AR.

We conclude that requirements for a suitable tangible and interface depend on the application scenario and, with this, on how much tangible interaction users perform. If 3D interactions like viewing an object from all sides are a main part of the application, users prefer a realistically shaped tangible. However, using a tangible that is similar to the virtual content in size and shape is not always possible. For example, if the tangible is too small, the AR application cannot detect and track it. Additionally, users can only comfortably grab it if it has a suitable size and weight. If the application requires users to hold the tangible still, like for watching animations, the users prefer the generic tangible because users can then hold the tangible on its handle or place it on a surface using the tripod. The combined tangible joins both advantages and adds interactivity through the plug connection system to an

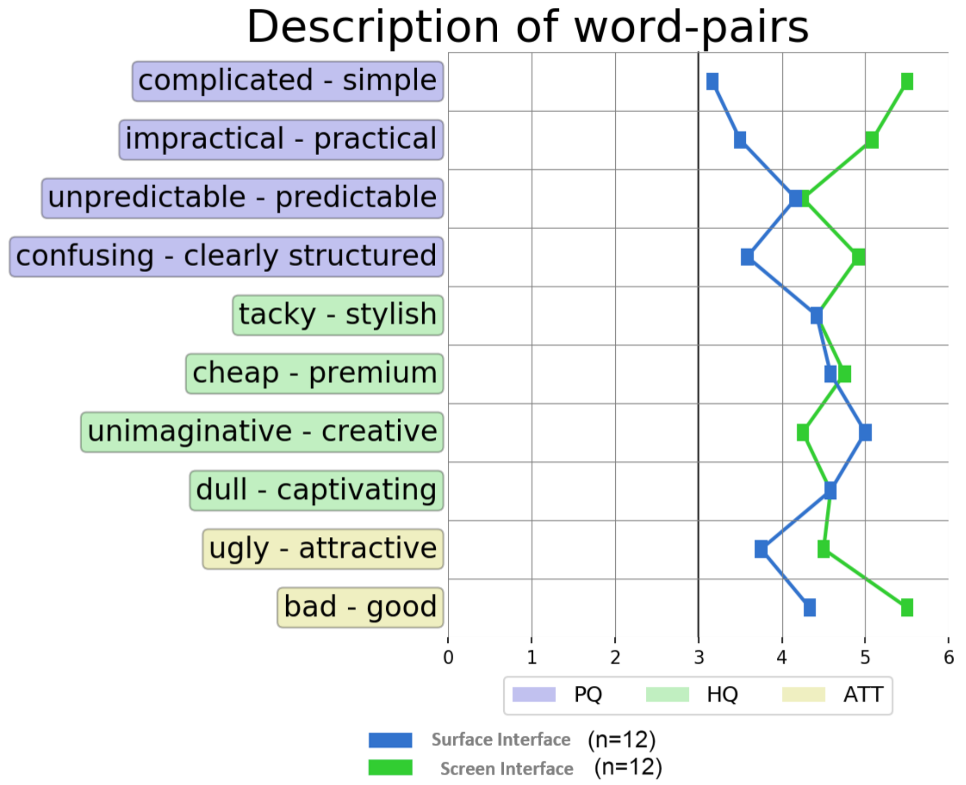

Figure 6: Analysis of the description of word pairs [HBK03] (screen interface in green and surface interface in blue).

application. Users explained that they liked the idea of plugging tangibles together. This shows that the combined tangible is a good compromise between tangibles with realistic shapes and generic ones.

6 Conclusions and Future Work

This paper introduced six interfaces and applied them to tangible AR use cases: screen, surface, realistically shaped tangible, generic tangible, combination, and combination with plug system.

We implemented a screen interface that was perceived positively and most suitable in a user study that evaluated the surface and screen interface. While the surface interface was also perceived positively, our participants had difficulties with their hand coordination. When comparing realistically shaped and generic tangibles interfaces, we showed that realistically shaped tangibles are preferred for applications with a focus on 3D content, for example, applications that explain an object's structure like the *show and tell* pattern. However, we pointed out that realistically shaped tangibles can also involve challenges in handling, depending on their size, shape, and weight. Additional challenges can occur in tracking and 3D printing realistically shaped tangibles. For applications where the focus is on a specific part of the virtual model, e.g., animations, users prefer to use our generic tangible. Our generic tangible includes a handle that users found helpful for rotating the tangible with one hand, and that can be used as a tripod. As both tangible types have different advantages and are preferred for different application scenarios, this work combined the advantages of the realistically shaped and generic tangibles. Additionally, it proposed to plug a realistically shaped tangible on top of our generic tangible. This way, handle and tripod functionality can be used in combination with a realistically shaped tangible. An additional advantage for the combined tangible is that the realistically shaped tangible does not have to be suitable for stable vision-based tracking. Instead, the generic tangible can be tracked.

Our results are based on a user study with a relatively small sample size of persons who classified themselves as laypersons in the field of AR. Therefore, the results indicate how persons without or with little experience in AR perceive the different interfaces with their advantages and disadvantages for different scenarios. With a larger sample size, or if the users had more experience or training, the results might differ from ours.

In future work, it can be researched how each interface can include more affordances. In this context, one can also think of further ways to combine interfaces. For example, we placed system functionalities for the realistically shaped tangible interface on the tangible's flat side. If the tangible has no flat side, it can be suitable to combine it with the surface or screen interface. Furthermore, it would be interesting to work on tracking issues and to evaluate all our interfaces. Finally, we plan to work on testing which interfaces are preferred in other application scenarios and if our findings can also be applied to further domains.

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References

[AIS77] Christopher Alexander, Sara Ishikawa, and Murray Silverstein, *A Pattern Language: Towns, Buildings, Construction*, Oxford University Press, New York, 1977, ISBN 0195019199.

[BGL05] Mark Billinghurst, Raphael Grasset, and Julian Looser, *Designing Augmented Reality Interfaces*, SIGGRAPH Computer Graphics **39** (2005), no. 1, 17–22, ISSN 0097-8930, DOI 10.1145/1057792.1057803.

[BKMS19] Vincent Becker, Sandro Kalbermatter, Simon Mayer, and Gábor Sörös, *Tailored Controls: Creating Personalized Tangible User Interfaces from Paper*, Proceedings of the 2019 ACM International Conference on Interactive Surfaces and Spaces (New York, NY, USA), ISS '19, Association for Computing Machinery, 2019, DOI 10.1145/3343055.3359700, pp. 289–301, ISBN 9781450368919.

[BKP08] Mark Billinghurst, Hirokazu Kato, and Ivan Poupyrev, *Tangible Augmented Reality*, ACM SIGGRAPH ASIA 2008 Courses **7** (2008), no. 2, 1–10, DOI 10.1145/1508044.1508051.

[DHRD21] Dagny C. Döring, Robin Horst, Linda Rau, and Ralf Dörner, *Sensory Extension of a Tangible Object for Physical User Interactions in Augmented Reality*, Proceedings of the 16th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications - HUCAPP, INSTICC, SciTePress, 2021, DOI 10.5220/0010230301530160, pp. 153–160, ISBN 978-989-758-488-6.

[DLB15] Dragoş Datcu, Stephan Lukosch, and Frances Brazier, *On the Usability and Effectiveness of Different Interaction Types in Augmented Reality*, International Journal of Human-Computer Interaction **31** (2015), no. 3, 193–209, ISSN 1044-7318, DOI 10.1080/10447318.2014.994193.

[Gib77] James J. Gibson, *The Theory of Affordances*, Perceiving, acting, and knowing: toward an ecological psychology (Robert E. Shaw and John Bransford, eds.), Hillsdale, N.J.: Lawrence Erlbaum Associates, 1977, pp. 67–82.

[HBK03] Marc Hassenzahl, Michael Burmester, and Franz Koller, *AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität*, pp. 187–196, Vieweg+Teubner Verlag, Wiesbaden, 2003, DOI 10.1007/978-3-322-80058-9_19.

[HD19] Robin Horst and Ralf Dörner, *Integration of Bite-Sized Virtual Reality Applications into Pattern-Based Knowledge Demonstration*, 16. Workshop der GI-Fachgruppe VR/AR (Paul Grimm, Yvonne Jung, Ralf Dörner, and Christian Geiger, eds.), Virtuelle und Erweiterte Realität, 2019, DOI

10.2370/9783844068870, ISBN 978-3-8440-6887-0.

[HF10] Steven Henderson and Steven Feiner, *Opportunistic Tangible User Interfaces for Augmented Reality*, IEEE Transactions on Visualization and Computer Graphics **16** (2010), no. 1, 4–16, DOI 10.1109/TVCG.2009.91.

[HW16] Anuruddha Hettiarachchi and Daniel Wigdor, *Annexing Reality: Enabling Opportunistic Use of Everyday Objects as Tangible Proxies in Augmented Reality*, Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (New York, NY, USA), CHI '16, Association for Computing Machinery, 2016, DOI 10.1145/2858036.2858134, pp. 1957–1967, ISBN 9781450333627.

[IU97] Hiroshi Ishii and Brygg Ullmer, *Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms*, Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems (New York, NY, USA), CHI '97, Association for Computing Machinery, 1997, DOI 10.1145/258549.258715, pp. 234–241, ISBN 0897918029.

[KBNR03] Boriana Koleva, Steve Benford, Kher Hui Ng, and Tom Rodden, *A Framework for Tangible User Interfaces*, Physical Interaction, (PI03) —Workshop on Real World User Interfaces, Mobile HCI Conference 2003, 2003, pp. 46–50.

[KKL09] Eun Kwon, Gerard J. Kim, and Sangyoon Lee, *Effects of Sizes and Shapes of Props in Tangible Augmented Reality*, 2009 8th IEEE International Symposium on Mixed and Augmented Reality, IEEE, 2009, DOI 10.1109/ISMAR.2009.5336463, pp. 201–202, ISBN 978-1-4244-5390-0.

[MIT] MIT Media Lab, *Tangible Media Group (TMG)*, `https://tangible.media.mit.edu/`, Accessed: June 30, 2023.

[PTC] PTC Inc., *Vuforia Engine Developer Portal*, `https://developer.vuforia.com/`, Accessed: June 30, 2023.

[RHLD21] Linda Rau, Robin Horst, Yu Liu, and Ralf Dörner, *A Nugget-Based Concept for Creating Augmented Reality*, 2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), 2021, DOI 10.1109/ISMAR-Adjunct54149.2021.00051, pp. 212–217.

[UI00] Brygg Ullmer and Hiroshi Ishii, *Emerging Frameworks for Tangible User Interfaces*, IBM Systems Journal **39** (2000), no. 3.4, 915–931, ISSN 0018-8670, DOI 10.1147/sj.393.0915.

[Uni] Unity Technologies, *Unity Real-Time Development Platform - 3D, 2D vR & Ar Engine*, `https://unity.com/`, Accessed: June 30, 2023.

[VML19] Dimitar Valkov, Andreas Mantler, and Lars Linsen, *Haptic Prop: A Tangible Prop for Semi-passive Haptic Interaction*, 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), IEEE, 2019, DOI 10.1109/VR.2019.8797718, pp. 1744–1748.

[Wil50] Frank Wilcoxon, *Some Rapid Approximate Statistical Procedures*, Annals of the New York Academy of Sciences **52** (1950), no. 6, 808–814, ISSN 0077-8923, 1749-6632, DOI 10.1111/j.1749-6632.1950.tb53974.x.

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