# A Tangible Object for General Purposes in Mobile Augmented Reality Applications

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**Abstract:** Smartphones and tablets are common technologies within today's private living environments. They are well-suited to serve as a platform for mobile Augmented Reality (AR). Tangible AR is a subclass of AR which includes tangible objects and can make interactions intuitive. With this, new options for human-computer interaction become available at home. Based on literature research and design rationale, we identify requirements that help to develop a tangible object which can intuitively be used as tangible user interface (TUI) for mobile AR applications. Users should be able to handle the tangible object comfortably. Additionally, it needs to be reliably trackable with today's tracking algorithms. The tangible object should also offer affordances to the users. We strive to develop a single, versatile object that is usable in different application scenarios at home. Our approach is to design a tangible object that combines different surfaces and shapes to offer various affordances and interaction possibilities. A physical instance of this object can be created with a 3D printer. We argue that this allows users to trigger actions intuitively in an AR environment or to manipulate virtual content.

**Keywords:** Tangible Augmented Reality; Mixed Reality; Tangible User Interface

## 1 Introduction

Current smartphones and tablets are suitable devices to serve as mobile Augmented Reality (AR) platform because they are equipped with a camera and have sufficient computing power. Furthermore, AR supporting software can be preinstalled with the operating system, e.g., ARCore on Android or ARKit on iOs. The wide distribution of such devices in private life offers new options for human-computer interactions that are available at home. With this, the number of available mobile AR applications is also increasing. Compared to traditional 2D interfaces, mobile AR applications offer other possibilities for user interactions. One category for such user interactions is physical interaction. Literature such as [BKP08] shows that the intuitiveness of user interactions can be improved when a tangible real-world object serves as user interface. Using this object, users can manipulate objects in their real-world to manipulate virtual content. AR experiences can be improved with the interaction techniques that tangible objects allow, because they can offer more affordances than solely virtual interfaces [Bu99]. The notion of affordance is discussed as properties of objects which invite for specific actions by Gibson [Gi77], e.g., a button suggests pressing or a door handle

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suggests levering it. Therefore, tangible objects could help users to have an intuitive tangible AR experience without frustration resulting from a non-intuitive interface.

In general, a large variety of objects can be utilized as tangible objects for a tangible user interface (TUI) in an AR application. Images or paper cards are commonly used as image targets and are popular for AR applications for private use. One 3D tangible object that is used for AR applications in private life is a cube, e.g., the merge cube [Me20]. While a cube can be a suitable object for viewing virtual 3D content, other objects could suggest more or other affordances. Thus, tangible objects providing affordances can help users to understand interaction possibilities for a mobile AR application without or with a short learning phase beforehand.

Our contributions in this paper are the following. Based on literature research and the elaboration of a design rationale, we identify and explore requirements for a tangible object that can be used as TUI for AR applications. We propose a generic tangible object that can be used in diverse AR application scenarios. It provides several geometrical forms which offer different affordances. With a 3D printer, we create a physical instance from our digital model and discuss which of its properties are conforming to our proposed requirements.

This paper is organized as follows. In the next section, we present related work. Following this, we identify and describe our three requirements. We applied our findings and designed our tangible object, which we introduce in section 4 and evaluate in the fifth section. We draw conclusions in section 6 and share our thoughts on future work.

## 2 Related Work

Early ideas for TUIs have been discussed in [WMG93]. Following this, Fitzmaurice et al. [FIB95] introduced their concept of graspable interfaces, where they use objects, e.g., handles, to manipulate digital content. These inspired the Tangible Media Group [IU97] for their vision of tangible bits, where the users' physical surrounding becomes an interface itself as objects or surfaces are linked to digital information.

Billinghurst et al. [BKP08] describe Tangible AR interfaces as an intuitive way to interact with an AR interface where users can manipulate a physical tangible object to manipulate a virtual object which is registered to the physical one. They describe design principles for TUIs which can help to develop an intuitive TUI for AR applications. They state that a Tangible AR interface that follows their design principles is intuitive to use and facilitates seamless display and interactions. However, they do not cover design principles for tangible objects but concentrate on functional requirements to the interface, e.g., support for multiple handed-interactions or multiple activities and objects. Furthermore, they propose four prototype AR applications with tangible interfaces: Shared Space, ARgroove, Tiles, and VOMAR. Planar images are used as tangible interfaces in Shared Space and ARgroove. For Tiles, the images have various shapes that are mapped to different semantics. The unique functionality of each image target is similar to the unique functionality of each icon and tool on a computer desktop interface. In VOMAR, they use a trackable cardboard paddle as tangible interaction device.

Different tangible objects have been explored to manipulate AR content. For example, a trackable pen is used for MARS [Hö99] and Studierstube [SFH00]. Other tangible objects for AR applications can be a cup, which allows users to modify virtual object [Ka03], or a cube [Ji15; Me20].

The tangible AR applications and interfaces named above demonstrate that different shapes and objects can be conceivable as tangible interfaces. Some tangible objects offer affordances for specific interactions but are dependent on the use case and cannot be reused in another context, e.g., images or objects that represent one specific real-world object. Generic tangible objects can offer affordances for general purposes and hence be used in several use cases. However, for some use cases, their affordances are not sufficient. For example, a pen offers affordances for tasks like writing and selecting, but no affordances for examining 3D content. In contrast, a cube offers the affordance to examine 3D content but no affordances for writing.

## 3 Requirements for a Generic Tangible Object in Tangible AR

We identified three requirements for a tangible object that is supposed to be used as generic AR-based TUI. In contrast to tangible objects that are developed for one specific use case, a generic object can be used for several applications. Therefore, it can contribute to a simple TUI where no switching between several objects is necessary. In this section, we go into detail for the three requirements.

This first category is the object's attributes to make it reliably detectable and trackable with current tracking algorithms. This is helpful to provide a frustration-free and immersive user experience. For example, when immersed in an AR experience, the users can feel present in the AR to the point that virtual content is not perceived as virtual but as part of the physical world. Then, whenever the tracking is lost, this illusion can be disturbed or completely disrupted. Additionally, users need to wait and eventually need to put either the tracked object or the AR device in another position or to change the lighting conditions before the tangible object can be detected and tracked again which further disturbs the AR experience. Therefore, the tangible object needs to consist of reliably detectable and trackable textures or shapes and surfaces. This is dependent on the used tracking algorithms because not all tracking algorithms detect or track the same properties. Such properties of an object can be its shape, features in its texture, colors, or a combination of these. Several tracking algorithms make use of more than one property because this adds to tracking stability. For example, the tracking software Vuforia detects objects by shape, but additional information about the material, such as colors, significantly improves the robustness [Pa20]. Therefore, a reliably trackable object should ideally combine multiple well detectable and trackable properties. When users hold the tangible object, they might occlude these properties in part or entirely, which can make the object hard to detect or contribute to a tracking loss. To provide enough detectable and trackable properties in despite of occlusion, each part or each side of the tangible object should be reliable trackable.

The second category we identified is the tangible objects' handling which includes its size, weight, and shape. A study by Sheridan et al. [Sh03] finds that tangible objects, in their case cubes, should naturally fit in the user's hand. We conclude this makes a recommended size for the tangible object dependent on the user's hand size. For example, a child can have smaller hands and require a smaller tangible object than an adult. A size of 8 cm × 8 cm × 8 cm is specified as suitable by Jimenez et al. [Ji15]. They use a webcam with a resolution of 2 megapixels and a focal length of 3.7 mm and find the resolution to be sufficient for target recognition with a distance of up to 1.5 m between object and camera. Furthermore, they state this is a mean value between sizes suggested by AR software developers. In their scenario, the user has both hands available and can choose to grab the object with one or both hands. However, in mobile AR users might be required to hold their AR device and therefore have only one hand left to use a tangible object as TUI. In this case, a smaller size can make the handling with one hand easier. Beside a tangible object's size, its weight influences its handling. Holding a tangible object can become exhausting for the user, especially if it is heavy. Therefore, we determined a tangible object should preferably be as light as possible, but yet durable, to make its usage less exhausting for users. A lightweight object is usually achieved without further effort due to a relatively small size. For example, a 3D printed cube of size 8 cm × 8 cm × 8 cm and with 25% infill (a common density setting) weighs about 150 grams. This value is dependent on the printing material, but common 3D printing materials have similar densities, except for metals. Furthermore, the tangible object's shape has an impact on its handling. The study by Sheridan et al. [Sh03] finds that an object's geometry affects how well users can grasp it. The authors state that curves in an object's geometry as well as a high surface area can enhance its grip. For example, they explain that a rhomboid or star-shaped object is easier to grasp than a cube. They also find that the object's material has an impact on its grip and that a flexible material can aid in grip.

We identified an object's affordances as third category. If specific properties of an object invite for certain actions, they offer affordances. This suggests that we can provide affordances for certain actions, that users can perform in an AR environment, by the tangible object's design. For instance, a hemisphere shape can be perceived as a button and therefore afford to push it. This indicates that various shapes can afford distinctive actions. Therefore, we suggest designing the tangible object consisting of various shapes, that each offer affordances for specific or several actions. General interactions, that a general tangible object could support and that can be useful in several AR applications, could be selecting, viewing 3D content, navigating, or scrolling.

## 4 Proposal of a Generic Tangible Object

Based on the requirements identified above, we designed an object that can serve as TUI for general purposes in AR applications and describe it in this section. The digital model of our tangible object is shown in Figure 1.

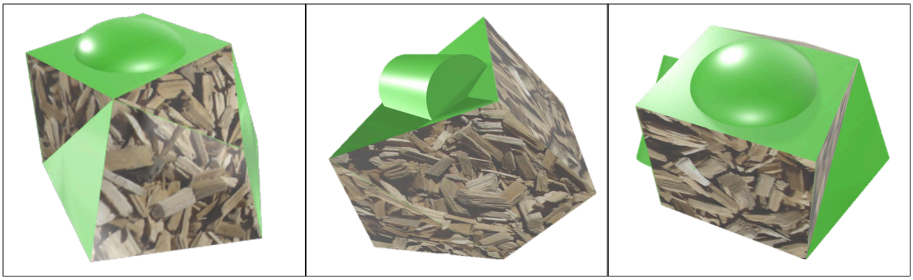

Fig. 1: Digital model of a tangible object for intuitively manipulating virtual content of an AR

We used Vuforia's image target example *chips* to create a texture for the tangible object. It was printed on adhesive film and glued to the object's surfaces. Because the image target is specifically designed to be detected and tracked, it provides a high number of trackable features. Besides this, trackable properties of our tangible object can be its edges and overall shape. The hemisphere and cylindrical shaped parts contribute to an asymmetric shape.

We use PLA material for 3D printing, which has a density of avg. 1.3 g/cm³. The PLA printing material is rigid and allows a firm grip without damaging or compressing the tangible object. Our object was printed at a size of 5.5 cm × 5.5 cm × 4 cm. The chosen infill density of 20% results in a weight of 23 g. The surfaces of our object include one pentagon, four quadrangles, and five triangles. The pentagon has a size of 5.5 cm × 5.5 cm at its widest place. The edges of two quadrangles are 2.8 cm, 2.1 cm, 3.6 cm, and 3.4 cm. A third quadrangle, which is a rectangle, has a size of 3.2 cm × 3.6 cm. From the fourth rectangle surface with size 3.6 cm × 3.0 cm, a hemisphere shaped part with 2.8 cm diameter and height 0.7 cm sticks out. Two of the triangles are isosceles. The first triangle has a base of 3.6 cm and a height of 2.0 cm while the second one has a base of 4.4 cm and a height of 2.2 cm. A third triangle measures 3.6 cm, 3.3 cm and 4.4 cm on its edges. A cylindrical shape (2.5 cm height and 0.7 cm diameter) sticks out from two further triangle surfaces which have the same sizes as the second and third triangle. This results in 28 edges, 16 vertices, and two round shapes. These various surfaces and shapes offer several affordances, depending on the use case. Our surfaces (triangles, rectangles, and one pentagon) can be augmented with different shaped images or virtual content. The cylindrical shape can suggest user interactions like scrolling, zooming, or turning over a page in a virtual book. Pushing a button or buzzer can be suggested with the hemisphere shape.

## 5 Evaluation and Discussion

We created a physical instance of our model using a 3D printer. We inspected how our proposed tangible object meets the requirements. Our results are described and discussed in this section.

Initially, the tangible object was printed with a 3D printer from a single material in one color. This provided few trackable features and the shapes' edges did not contrast well from the rest of the object. Therefore, the object could not be detected by the tracking software. To improve the object's tracking conditions, we applied a texture to both, the tangible object and its digital model. The digital model with UV mapped texture can be used as a reference for the tracking algorithm. However, gluing the texture on the tangible object is imprecise. With these differences between the physical object and the digital one, the tracking performance is insufficient. Another approach is to scan the physical object to use the scan data as a reference for the tracking algorithm. In this case, suitable lighting conditions must be provided during the scan process. With this approach, our tangible object can be tracked well while the lighting conditions are similar to the ones during the scan. The surface that the object rested on during the scan process is not included in the scan data. Therefore, it cannot be detected or tracked. A second scan from another side is required to make the tangible object reliably trackable from all sides. This process is sufficient but time-consuming.

Our 3D printed object is designed for one-handed interactions in mobile AR and therefore relatively small. Depending on the user's hand size, this can result in occlusion of a substantial number of trackable features or properties and therefore disturb the tracking quality. We find the object can comfortably be grabbed on its edges so that only a few parts are occluded. This is visualized in Figure 2.

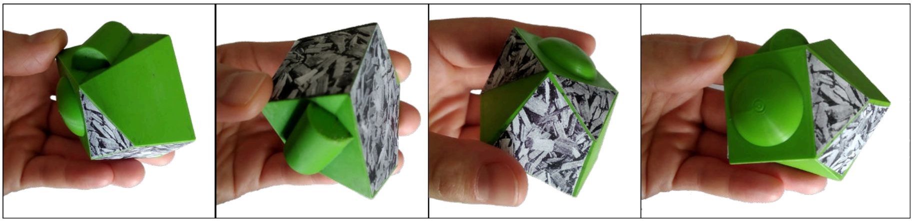

Fig. 2: Views of a tangible object for intuitively manipulating virtual content of an AR

## 6 Conclusion

With this work, we explored three requirements for intuitive tangible objects serving as TUI for mobile AR applications: tracking conditions, handling (weight, size, shapes), and affordances. We proposed an example for such a tangible object where we considered these. Based on our three requirements, our object is indicated to be suitable for intuitive interactions in an AR environment.

In future work, our proposed tangible object can be improved regarding its size and trackable properties or features. We found our size of 5.5 cm × 5.5 cm × 4.0 cm acceptable, but a greater size would result in less occlusion and therefore can contribute to a stable tracking. We applied a texture to our object to make it reliable trackable, but this made a time-consuming scanning task to set the object with texture as reference for the tracking software necessary. Future work can include developing 3D-printable textures that can easily be detected and tracked with current tracking algorithms.

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