When Realities Interweave: Exploring the Design Space of Immersive Tangible XR

Jakob CarL Uhl
jakob.uhl@ait.ac.at
AIT Austrian Institute of Technology
Vienna, Austria
University of Salzburg
Salzburg, Austria

Helmut Schrom-Feiertag
Georg Regal
helmut.schrom-feiertag@ait.ac.at
georg.regal@ait.ac.at
AIT Austrian Institute of Technology
Vienna, Austria

Linda Hirsch
Yannick Weiss
linda.hirsch@ifi.lmu.de
yannick.weiss@ifi.lmu.de
Ludwig Maximilian University
Munich, Germany

Manfred Tscheligi
manfred.tscheligi@sbg.ac.at
University of Salzburg
Salzburg, Austria
manfred.tscheligi@ait.ac.at
AIT Austrian Institute of Technology
Vienna, Austria

ABSTRACT

Tangible devices and interaction in Extended Reality (XR) increase immersion and enable users to perform tasks more intuitively, accurately and joyfully across the reality-virtuality continuum. Upon reviewing the literature, we noticed no clear trend for a publication venue, as well as no standard in evaluating the effects of tangible XR. To position the topic of tangible XR in the TEI community, we propose a hands-on studio, where participants will bring in their own ideas for tangible XR from their application fields, and develop prototypes with the cutting-edge technology and a selection of virtual assets provided. Additionally, we will collectively reflect upon evaluation methods on tangible XR, and aim to find a consensus of a core evaluation suite. With this, we aim to foster a practical understanding and spark new developments in tangible XR and its use cases within the TEI community.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**; **Mixed / augmented reality**.

KEYWORDS

tangible interaction, extended reality, mixed reality, virtual reality, fiducial markers

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1 DETAILED PROPOSAL DESCRIPTION

The Reality-Virtuality Continuum, as defined by Milgram in 1994 [18] describes the transition from the physical world to completely virtual environments. Whereas Virtual Reality (VR) represents complete virtuality, Augmented Reality (AR) and Augmented Virtuality (AV) represent hybrid forms on the continuum, summarized under the term Mixed Reality (MR). In recent years, a new umbrella term encompassing MR and VR has emerged: Extended Reality (XR). The integration of immersive tangible interaction in XR (i.e., MR and VR) has shown to increase the sense of presence [12], performance [9], and to decrease mental load [7] of applications. In a review of the literature concerned with evaluations of tangibles in XR (see Fig. 1 for an overview) we observed that that (i) papers are published in a variety of venues, without one central hub and (ii) many papers on tangible interaction in XR do not report any evaluation of their respective proposed systems. Due to the essential role of tangible interaction in making XR more immersive and realistic, it could benefit greatly from a better integration at the TEI conference.

The goal of the proposed studio is to provide a hands-on opportunity for participants to discover the design space of immersive tangible interaction in XR and to reflect upon the methods of its evaluation. By that, we want to explore the impact of different levels of tangibility on the reality-virtuality continuum, considering a broad range of tangible interaction in the discussion (including, e.g., wearable skin interfaces, shape shifting, temperature, ...).

We will provide MR and VR setups with (a) fiducial markers and (b) active trackers which can be attached to real objects (a selection of which we will provide, participants may also bring their own objects) to integrate them into XR as interaction devices. We will present a demonstration of a use case of immersive tangible XR from the field of medical training at the beginning of the studio, after which the participants will split up into groups and tinker with the provided tools and materials, such as the different trackers or markers, vibration motors or temperature generators. Potential use cases will be identified in brainstorming sessions within the groups and will then be implemented during a prototyping session.

The developed interactions and prototypes will be presented by the teams, and a final discussion about the possibilities and limitations of immersive tangible XR will be moderated and accompanied by a questionnaire, to gather feedback regarding the use of tangible XR and its evaluation. In this discussion we will also discuss alternative tracking methods (e.g. vision-based approaches). We further plan on recording the reflections of the participants during the discussion, the developed XR prototypes and questionnaire results to write a collective position paper, summarizing the findings of this exploration.

2 GROUNDING IN THEORY

Tangible interaction in XR is achieved in various ways. For one, fiducial markers (Fig. 2) are used in AR and MR to track physical props, enabling them to be tangible interaction devices in XR. In VR, devices like the Vive Tracker [1] together with inside-out tracking with lighthouse technology are used to track the position in space of objects that they are attached to, enabling tangible interaction.

Fiducial markers are used commonly in a direct metaphor: when the object that was used for tangible interaction represented the virtual representation exactly. In the case of [17] or [19], for example, chemical lab equipment was augmented in MR with the use of markers to teach sequences in experiments. Handheld electronic devices were tested on their usability by creating a dummy model, that was augmented with marker based AR to show content on the displays by [16, 20–22]. Tangible buttons in VR [14] or a tangible photo album [13] were achieved in a similar way.

Another type of tangible device in the literature are tangible cubes, implemented with fiduciary markers. These cubes are a more abstract interaction metaphor and allow for modular arrangement of whatever they are representing in XR. In [10], for example, a tangible cube widgets allows for playful interaction with an AR tabletop display, changing parameters in a simulation by placing and turning it differently.

To overcome the positional restrictions involved with using passive physical props in XR, researchers proposed redirecting the user's walking [23] or grasping [1] to allow a single physical object to stand in for multiple virtual ones at differing positions. Furthermore, visuo-haptic illusions have been shown to be able to alter the perception of haptic properties of physical props based on visual stimuli, including their shape [3], size [4], weight [24], and stiffness [29]. This enables the simulation of a wide range of virtual objects with various properties using fewer props.

Tangible devices and interactions in XR have been associated with various outcomes regarding human experience. We identified *experience, performance, usability, task-load, presence, attention and social interaction* as the main investigated outcomes. Tangible alternatives to conventional interaction in XR often lead to more satisfaction [11], enjoyment ratings [25] or interest [17] in terms of user experience. Regarding performance, tangible interactions in XR can lead to faster completion times of tasks and higher accuracy [9], as well as less mistakes in learned tasks [26]. Usability is mostly

[1] https://www.vive.com/us/accessory/tracker3/

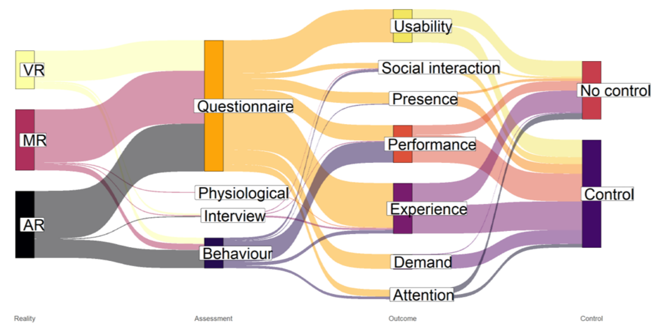

Figure 1: Sankey diagram of tangible XR literature. From left to right: type of reality, type of measurement, type of outcome and whether a control group is used or not.

reported as similar to conventional interaction in XR [8], which is promising given that research papers are often based on prototypes.Further, tangible interaction in XR has also been associated with a reduced mental load of tasks [7]. Presence was mostly rated higher or at least the same when tangible interaction was used [6, 12]. In the works concerned with attention, tangible interaction led to higher situational awareness [27], perception and engagement [5, 15, 27]. Lastly, tangibles enabled increased collaboration [26] and an increased quality of these interactions [28].

Overall, the effects of tangible interaction in XR show a lot of promise in various application fields like health, education or collaboration. Given the recent increased emergence of this field, we think it is also time to develop more unified approaches in evaluating tangibles in XR, which will be one of the discussion points in the studio.

3 MATERIALS TO BE EXPLORED

We want to explore the design space for tangible interaction along the reality-virtuality continuum, with a main focus on the shift from VR to MR and vice versa. For that, we will provide two Varjo XR-3 setups, including a chroma-key mat and printed fiducial markers. The markers will partly be applied to a selection of objects we will provide, that serve as starting points and demonstrators for tangible objects in MR. Participants will also be able to bring their own objects / devices and apply the provided markers to them. Similarly, to explore the space of tangible VR, we will provide two HTC Vive Pro Eye Setups, including Vive trackers. This will serve as a contrast and comparison to the more modern Varjo XR-3 setup, while still enabling hands-on experience. In both setups, a virtual testing space will be provided within the unity game engine, including a selection of interaction templates. To enable asymmetric, yet synchronous communication among participants we would propose - and if necessary provide - four big displays, to mirror the respective setup.

4 LEARNING GOALS

Given the many use cases for tangibles in XR and the multitude of possibilities, where on the reality-virtuality continuum they can be implemented, we pose the following research question:

(a) Varjo XR-3 **(b) HTC Vive Pro Eye** **(c) Fiducial markers (top) & Vive trackers (bottom)**

Figure 2: MR / VR head mounted displays and trackers enabling tangible XR.

RQ: Given an use-case of tangible XR, where on the reality-virtuality continuum should an application be developed?

As a sub-topics of this RQ we want to investigate the level of tangibility needed for a given use case, as well as the impact on presence of tangible XR.

To answer these questions, we will identify use cases from the participants, develop AR, AV or VR prototypes and reflect upon how tangibles in XR should be evaluated. As an outcome, we want to provide recommendations for practitioners which level of virtuality to use to create more immersive experiences and how to evaluate their applications.

4.1 Goal 1: Discover potential use cases

We invite professionals from different fields to introduce their topics and application fields into this session, in order to identify new potential use cases and applications of tangible XR.

4.2 Goal 2: Hands-on experience

By providing the hardware, real and virtual assets as well as scripting templates, we enable participants to gain practical experience with the technology. According to constructivist learning theory [2], the best way to learn is to be an active learner, try out concepts for oneself and reflect upon the learning experience afterwards. Therefore, in giving the participants the tools and the space to try out tangible XR technology, we aim to foster new knowledge and ideas for uses within the TEI community in the future.

4.3 Goal 3: Reflect upon evaluation methods

Lastly, we want to start an ongoing discussion of evaluation methods in the field. In our review ot the literature, we noticed a multitude of different outcomes, questionnaires and measures, which makes it hard to compare tangible devices in XR. By reflecting on this collectively, we aim to find common ground in what the participants think should be a core of a evaluation of tangible XR.

5 SCHEDULE

The studio will be held as a one-day event. The workshop will start with an introductory talk followed by a hands-on demonstration of an immersive XR prototype with tangible equipment. After that, participants will present their position statements and the topics they would like to explore. This will be followed by an in-detail explanation of the XR hardware and the tracking possibilities. Building on the presented statements and topics the participants will jointly work on developing research prototypes and planning novel concepts to evaluate those research prototypes. Overall the goal is to provide a strong hands-on experience where all participants can experience the technologies and participate in the design and development activities. Lastly - depending on the conference schedule - we will host a voluntary social dinner networking session in the evening.

6 PLAN FOR THE IN THE EVENT OF A HYBRID/VIRTUAL CONFERENCE

To enable hybrid participation, we intend to live stream the whole session. By combining the virtual view with a physical camera placed in the room, we will enable viewers to see both the virtual and the real world in parallel. Online participants will be able to present their topics and use-cases they want to address during the session, and will form online groups to work on their concept designs. For that, an online whiteboard space will be provided and moderated. As online participants can not experience the technology hands-on, they will be provided the digital assets and as an alternative activity will create virtual components like 3D models, interaction scripts or environments. In the wrap up, the online participants will also present their conceptual prototype and join in the discussion. Alternatively, we could also provide a VR workspace for participants who own a VR headset, to enable a more direct and social form of brainstorming in the virtual space.

7 SUPPORTING DOCUMENTS/FIGURES/MATERIALS

As a demonstrator, we will present a prototype of a MR medical training manikin (Fig. 3), which is being developed within one of our projects. This will serve as a primer and an example, how tangible XR can be applied to a specific use case. The demonstrator uses chroma key compositing as well as fiducial markers in combination with the Varjo XR-3 to enable tangible interaction with the manikin in an immersive virtual environment.

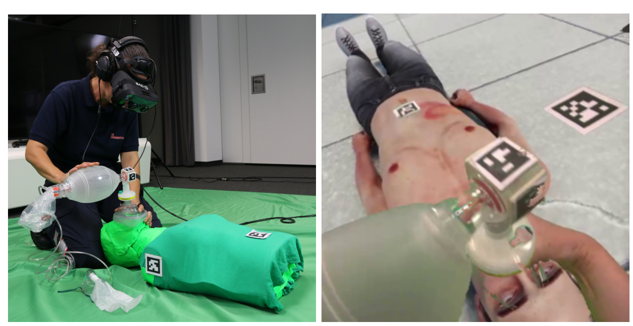

Figure 3: MR manikin (left) and virtual view of the user (right), which will be demonstrated during the studio session.

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