EUROGRAPHICS Workshop on Graphics and Cultural Heritage (2017)
R. Sablatnig and B. Štular (Editors)

Short Paper

Hybrid Virtual Reality Touch Table - An immersive collaborative platform for public explanatory use of cultural objects and sites.

Erik Sundén[1], Ingemar Lundgren[2] and Anders Ynnerman[1]

[1]Linköping University, Department of Science and Technology, Norrköping, Sweden
[2]Ocean Discovery, Västervik, Sweden

Figure 1: *Various applications, such as exploration of 3D reconstructed data of sunken 16th century ship, and various focus groups, such as kids, where the hybrid virtual reality touch table has been utilized.*

Abstract

In this work we present an interactive and immersive solution for scientific data exploration which target visitors to museums and science centers, where the visitors themselves can conduct self-guided tours of scientific data, such as 3D scans of objects with cultural, historical or archaeological importance. The solution consist of a interactive multi-touch table with intuitive user interfaces, combined with head-mounted display and optional wireless controller. A visitor can explore the scientific data, but also a virtually created environment of the historical object(s), where found and acquired, which may be impossible for the visitor to visit and explore in real life. Visitors can work together to explore the data in close detail as well as guide other visitors in an explanatory manor. This interactive learning experience is designed to be versatile and suitable for visitors of various ages or with disabilities, by combining numerous views of the data as well as numerous interaction techniques to explore the data. Our approach and realization was created for the use case of an exploration application with reconstructed data of a sunken 16th century ship, which physically still lies on the seabed. Our motivation to create interactive stories along with as useful explanatory tool for domain experts lead us to this multi-purpose approach.

CCS Concepts

•***Human-centered computing*** → ***Collaborative interaction;*** *Auditory feedback; Touch screens; Virtual reality;*

1. Introduction

Graphical UI design is the foundation for intuitive user interfaces, which in many cases are application-specific, but also user-oriented, from novice to expert. Generally, in the field of visualization, the use of visualization is separated into exploration, analysis and presentation, typically applying different approaches to both interaction and user interfaces for each step. While the exploration phase requires flexible interaction method(s), the presentation phase should include views and user interfaces which are easy to understand for any user, and as such, usually are limited to a few predetermined parameters.

In this work, we focus on exploration and presentation of 3D data, and provide a suitable and versatile platform, which can be utilized to engage an audience and explain the data, as well as let numerous novice and/or expert users explore the data. It is also preferred that the exploration phase can be collaborative such that the numerous novice and/or expert users can take part in either the exploration or presentation phase of the data. This makes the application more engaging for an audience and user basis of various ages (such as families) and multi-purpose, as expert on the data can still perform partial control of the exploration, while a novice user can also conduct interesting and meaningful operations. Our target

DOI: 10.2312/gch.20171300

application in this work was to create a suitable way to collaboratively explore a digital reconstruction of a 16th century ship which is still lying on the seabed. The complete 3D reconstruction of this ship will in the end be of very high detail, thus users needed to have the possibility to explore the ship in close detail.

Most collaborative setups require a platform with a large form factor to interact with. A large (> 40") touch screen(s) has the benefit of providing intuitive natural interaction and can easily be intriguing for numerous people at the same time, as they can function as a good overview of the data for all viewers. However, large high-resolution such as 4K touch screens are relatively expensive, while having the benefit of being durable in a public exhibition. But more importantly, while zooming is possible to examine parts in close detail, the viewers interact with 2D projection of the 3D data.

A technology which enables users to emerge themselves in a digital world and explore virtual objects in close detail is HMDs (head-mounted displays). Recently, many vendors (such as Google, Facebook and HTC) have put significant effort into commercial virtual reality and HMDs, which has made hardware significantly cheaper and better, and also with significantly lower thresholds for content developers. The HMDs generally have high resolution, but for a wider field of view then regular desktop displays. The user interaction when wearing an occlusive HMD is commonly a hand-held controller(s), such as a gamepad, which for many users can be considered less familiar and/or approachable compared to a touch screen interface with gesture recognition [OI12]. However, the concept of introducing a new experienced technology might also have a benefit if you you account for that the experience of trying something new is also an important aspect of inspiring visitors. When exploring cultural heritage data, VR simulations can be considered having superior precision and interactivity to many other forms of exploring such data [FPMT10].

Based on these aspects, we decided to create a hybrid concept for our application, with multiple views and interactions alternatives, by combining the concept of exploring 3D data on a large touch screen, with the concept of exploring data with a head-mounted display (HMD). This hybrid concept was designed for the purpose of having an exploration and presentation tool of 3D data with focus on historical objects and environments.

Both novice and expert users should feel that the concept is useful, and as such, detailed exploration of the 3D reconstruction of physical objects, and a virtual construction of the objects environment, is both of high significance. This concept opens up the possibility of multiple views of the historical objects and sites, which utilize the strength of the hardware, in terms of resolution and interaction, but also the fact that these two interaction methods and views may have different suitability to different type of users.

Furthermore, for good accessibility purposes, an application utilizing a large touch screen as it's only interface to explore and interact with the data would need to design the UI and configure the screen placement such that view and interaction would be wheelchair accessible if placed in a public science center. This would introduce limitations on placement and presentations capability to the audience, which is of significant priority when designing an installation/application to be used in a public space such as a science center [SBJ*14].

2. Related Work

The concept of movable table with large mounted touch screen has been utilized in numerous applications across science centers [Gel06, Hor08, LRF*11, YRA*16], for the purpose of exploring data interactively in applications using real-time rendering. Much work has been done towards utilizing a touch screen as interaction with scientific data, both while viewing the content directly on the touch screen device [YSI*10, KGP*12], or in-directly by viewing the content on an additional display [BIAI17]. Touch interaction is by itself and interaction method superior to common desktop techniques when utilized as exploration technique of a vast variety of people when exploring interesting digital data at a public space such as a museum [HMDR08]. These techniques have also been utilized for exploring scientific data of historical and cultural importance, for novice visitors to public museums or for expert scientist [YRA*16].

Substantial amount of work has also been performed with touch interaction in virtual reality. Coffey et al [CKK10] introduced the concept of combining multi-touch table and stereoscopic wall. They further extended this setup for use within exploring scientific data, in particular volume datasets [CML*12]. Hachet et al [HBCdlR11] combined the multi-touch interaction with stereoscopic viewing on the same surface, for a direct interaction on a 2D UI while always seeing the 3D data and controlling it through indirect interaction. Bruder et al [BSS13] discuss the essential difficultly of combining a stereoscopic display with multi-touch, as the interaction surface and the appearance of the data in stereo are not co-located in depth. Marton et al [MRB*14] created an approach with both direct interaction on a touch table and pointerless indirect interaction to visualize artifacts in a public space. Balsa Rodriguez et al [RAB*16] extend this further by evaluating the large interaction environment to small mobile solutions with a direct interaction approach of exploring the data. All these cases are closely related to augmented reality, as the user can physically see the touch screen/device, and exploring the content on a mono or stereo-capable display which is not an HMD.

Wang et al [WL14] combined a HMD and a multi-touch interaction surface, by utilizing a non-occlusive HMD such that the user is able to view and interact with a multi-touch-enabled tablet mounted on the forearm. While this opens the possibility for utilizing a low-cost touch device for natural interaction, all common HMDs to-date are primarily occlusive, such that the user can be totally immersed in the virtual reality environment.

Gugenheimer et al [GDW*16] introduced *"FaceTouch"*, a combination of an occlusive HMD with a touch interaction surface mounted at the front of the HMD. The user cannot see the touch surface when wearing the HMD, but can still interact with it properly through their proprioceptive senses, an approach which has been previously introduced in virtual reality by Lopes et al [LIM*15].

But no substantial work has recently been made utilizing a modern occlusive HMD for virtual reality and a modern large multi-touch screen, which is also due to the fact that most virtual reality solutions try to design the concept for one single user, and not using it for a collaborative use case. In a collaborative case, the interaction itself can also be seen a communication channel between the users, or between the presenter and the audience [SBJ*14].

Much of collaborative work in past years for virtual reality has been on various approaches where collaborators share the same type of views of the data [ABM*97, BK99, HBGA03, SKSK09]. Our work is contrary to this focused on collaboration between numerous people on the touch interaction surface, but also with a single individual using an occlusive HMD and an optional controller.

Gugenheimer et al [GSFR17] recently introduced a proof-of-concept which utilize asymmetric interaction between a user in HMD and user(s) in non-HMD. By using floor projection and mobile displays in combination with positional tracking they can visualize the virtual world for the non-HMD user(s), enabling them to interact with the HMD user.

Ibayashi et al [ISS*15] has introduced a proof-of-concept named *"DollhouseVR"*, which shares many aspects with our approach. They combine an occlusive HMD with multi-touch table where designer(s) interact with a "god-like" 2D view on the table and an occupant wearing the HMD which is virtually inside the room environment and communicates with the designer(s). We utilize similar hardware setup and configuration/views for our approach, however with additional views on the table and other interaction choices (like physically moving the position of the HMD user) to make the table or the HMD both work as standalone exploration tools if desired.

The concept of using virtual reality for enhancing or assisting cultural exploration and/or experiences has been previously introduced. Pletinckx et al [PCKS00] offered visitors more intriguing views of ancient life at Ename through an on-site virtual reality installation. Gaitatzes et al [GCR01] analyzed virtual environment experiences developed at an education institution and outlined the issues in developing immersive interactive virtual archeology projects for the broad public. Further work has been made with building, managing and interacting inside the virtual environments with focus on cultural heritage [WWWC04, WOFK13]. However, not much work has been focused on collaborative virtual reality exploration of environments with cultural significance.

Benko et al [BIF04] presented a experimental tool for archeology researchers and students named *"VITA" (Visual Interaction Tool for Archaeology)*, an collaborative mixed reality system for off-site visualization of an archaeological dig. They utilize a non-occlusive HMD combined with a multi-touch projected table surface, and several other tracked hand-held displays. Our approach is also designed to be possibly used for archeology researchers, however we also target museum or science center visitors of various ages, and utilizing current low-cost occlusive HMD devices.

3. Exhibition trials of the hybrid VR touch table concept

The research presented in this paper is conducted in the context of a public science center, open 7 days a week with interactive scientific exhibition for the general public. With these facilities available, we decided to perform a trial use case of the hybrid virtual reality touch table in our public spaces, before we had any data of the 16th century ship. The target group was specifically younger people and their families, based on indications that they would be keen on utilizing an HMD for some family members, while adults or siblings/friends would feel intrigue to interact and collaborate with the HMD user. Thus, we created a collaboratory family-friendly survival game, as seen in figure 1(the two right sub-images). In the game, one user, the "shooter", is wearing the HMD and holding a game controller to control the movement of the virtual character, in first person view, in the direction of sight of the HMD device. Another user can utilize half the area of the touch table for a god-like interaction [SPT06], viewing the shooter in the center of the viewport. The touch table user can either drag or teleport the virtual shooter, i.e. changing the virtual position of the HMD user, by single finger touch interaction on any point surrounding the shooter. The type of movement is controlled by the HMD users controller, and thus the touch table users ability to affect the gameplay can essentially be disabled by the HMD user while still wearing the HMD. The experience was designed in such a way that HMD user benefited from collaborating with someone, to have higher total score, by voice commands and additional control by the collaborator on the touch table.

By combining both god-like interaction on the table and first-person view we achieved both *exocentric* and *egocentric* interaction [PI99], with the *egocentric* interaction by the HMD user being totally independent if desired. We learned that this approach could feel both natural, intriguing and comfortable for numerous users. The installation was placed in the exhibition area for several weeks, and multiple families appreciated the aspect of interacting together. During this time we learned that the additional cost to take into account is increased effort in maintenance and support compared to just using a touch table, which could be expected. It was not an issue that people did not read the instructions, and needed demonstrations, but that regular cleaning of the HMD was needed. We also had to remove the integrated headphones from the HMD after some time, partly because it was easier to communicate to the HMD user, but primarily because they where obliviously more fragile then mounting speakers on the table. It should also be noted, that a HMD is obliviously more fragile then a touch table in general, something to take into account when using such equipment in a public environment.

4. Applying the hybrid VR touch table concept to virtual exploration of the 16th century ship on the seabed

With partially completed reconstruction available we further developed our concept towards scientific exploration of the 16th century ship wreck as planned. The ship in question is named "Mars", which when sunken in 1564 off the coast of a Swedish island called Öland, was perhaps the biggest ship in the world at the time with over one hundred guns and 700 men onboard. It was discovered on the sea bottom in 2011, very well preserved for such age.

Ocean Discovery, a company of professional divers in Västervik, Sweden, that assists in maritime archeology, has used photogrammetry to produce a 3D reconstruction of the 60 m long wreck, with approximately 20,000 images, each of 36 megapixel resolution. This process is highly favorable towards bringing the ship out of the ocean, which would have been expensive and could also cause significant harm to artifacts. The 3D model is close to photo-realistic and scientifically accurate with an accuracy of less than 2 cm.

In this application we decided to let the HMD user take the roll as a diver exploring the wreck site. As previously mentioned, we wanted users to explore the ship in close-detail, due to the high precision scans available. This led us to create 3 different views on the touch table, as seen in figure 2. One large "god-like" view with an *exocentric* approach to the touch interaction of moving the diver to any position of the wreck, in three dimensions, utilizing one to two finger gestures for panning and zooming(pinch gesture). One view featured the virtual diver in 3rd person, where the HMD orientation was NOT respected. We introduced this view based on previous experience we have seen with visitors/audiences wanting to explore the details of the virtual environment as seen by the HMD user, but after sometime they could not follow the rapid movements of the HMD user without feeling dizzy/nauseous, as they are essentially passengers on what could be felt like a roller-coaster. The last view consisted of the first-person view of the diver/HMD user, respecting the HMD direction, which collaborators or visitors can also follow or glanze at if desired.

The model used in this application prototype is not the finalized version, as it is neither complete, nor is it full resolution. The user can choose to explore the 3D reconstruction from the outside or inside, or choose to explore a created 2D photomosaic of the wreck site, with a resolution of 24576*16384 pixels. This is controller through either a touch-enabled UI, or by using controller buttons. Furthermore, the user(s) can interpolate between moonlight to sunlight on the wreck site, controlled by a slider on the touch table, and a joystick on the controller, for exploring the wreck in various lighting conditions.

This setup enabled us to take the possible interactions a step further then the prototype of the survival game, and essentially create both an collaboratory *exocentric* interaction model (the touch table) and an *egocentric* interaction model (the HMD and game controller) which can be individually used to fully utilize the available exploratory options of this application. By other words, a user can either just use the touch table without touching the HMD and game controller, or just use the HMD and game controller without touching the table to explore every part of the sunken ship.

We also took the concept of "Object Impersonation" in virtual reality in mind, which allows the diver/HMD user to not only manipulate a virtual object from outside, but also become the object, and maneuver from inside [WL15]. Essentially the HMD user can interact with the table and discard the game controller, and switch between the HMD omnidirectional view and the touch table views, as seen in figure 1 and 3, which might be more comfortable for some individuals, as it would decrease the risk of nausea.

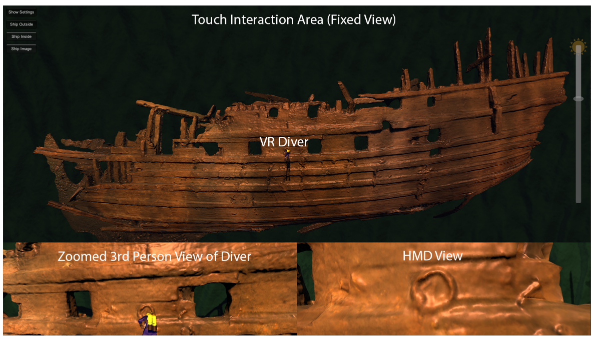

Figure 2: *Touch display views for the sunken ship application.*

5. Technical Realization

We utilized a 42" touch-enabled(optical) display, mounted on-top of a table fitted with wheels. We utilized the Oculus Rift (with Xbox One controller) as HMD device and optional controller, as it is well-adapted for a seating/standing still VR application purpose. The Oculus Rift did, due to it's fitting create a narrow field of view around the nose such that some users could see the real-world, meaning some users could see the touch table while wearing the HMD. All applications where created with the Unity game engine.

6. Conclusions & Future Work

In this paper we describe our approach for combining an occlusive HMD with a large movable touch table, for an exhibition installation and exploratory setup which takes less space compared to room-scale virtual reality experiences. Furthermore, we introduce complementary interaction options and views on the data for collaboratory tasks between HMD user and touch surface user, while also supporting the option of exploring the data of cultural significance in detail with only the occlusive HMD or only the touch table, thus supporting a vast variety of people which are intrigued or comfortable with only one of these exploratory alternatives, or which can only properly use one of them, due to accessibility, such as requiring a wheel-chair. Additionally, the audience/visitors can always view the touch table and the various viewports to get a detailed picture on what aspects of the data the user(s) are currently exploring, and the position of the user relative to the full overview.

We plan to continue with utilizing the full 3D reconstructed data of the sunken chip when ready, and to then use the data with our hybrid virtual reality touch table concept available to multiple science centers and other institutions.

Acknowledgement

This work has been conducted within the Norrköping Visualization Center C with partial funding from the initiative Visual Sweden.

Figure 3: *Live virtual exploration of the wreck site of the 16th century ship using the hybrid virtual reality touch table.*

References

[ABM*97] AGRAWALA M., BEERS A. C., MCDOWALL I., FRÖHLICH B., BOLAS M., HANRAHAN P.: The two-user responsive workbench: Support for collaboration through individual views of a shared space. In *Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques* (1997), SIGGRAPH '97, pp. 327–332. 3

[BIAI17] BESANCON L., ISSARTEL P., AMMI M., ISENBERG T.: Hybrid tactile/tangible interaction for 3d data exploration. *IEEE Trans. on Visualization and Computer Graphics 23*, 1 (2017), 881–890. 2

[BIF04] BENKO H., ISHAK E. W., FEINER S.: Collaborative mixed reality visualization of an archaeological excavation. In *Proceedings of the 3rd IEEE/ACM International Symposium on Mixed and Augmented Reality* (2004), ISMAR '04, pp. 132–140. 3

[BK99] BILLINGHURST M., KATO H.: Collaborative mixed reality. In *Proceedings of the First International Symposium on Mixed Reality* (1999), pp. 261–284. 3

[BSS13] BRUDER G., STEINICKE F., STURZLINGER W.: To touch or not to touch?: Comparing 2d touch and 3d mid-air interaction on stereoscopic tabletop surfaces. In *Proceedings of the 1st Symposium on Spatial User Interaction* (2013), SUI '13, pp. 9–16. 2

[CKK10] COFFEY D., KORSAKOV F., KEEFE D. F.: Low cost vr meets low cost multi-touch. In *Proceedings of the 6th International Conference on Advances in Visual Computing - Volume Part II* (2010), ISVC'10, pp. 351–360. 2

[CML*12] COFFEY D., MALBRAATEN N., LE T., BORAZJANI I., SOTIROPOULOS F., ERDMAN A. G., KEEFE D. F.: Interactive Slice WIM: Navigating and Interrogating Volume Data Sets Using a Multisurface, Multitouch VR Interface. *Transactions on Visualization and Computer Graphics 18*, 10 (2012), 1614–1626. 2

[FPMT10] FONI A. E., PAPAGIANNAKIS G., MAGNENAT-THALMANN N.: A taxonomy of visualization strategies for cultural heritage applications. *J. Comput. Cult. Herit. 3*, 1 (July 2010), 1:1–1:21. 2

[GCR01] GAITATZES A., CHRISTOPOULOS D., ROUSSOU M.: Reviving the past: Cultural heritage meets virtual reality. In *Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage* (2001), VAST '01, pp. 103–110. 3

[GDW*16] GUGENHEIMER J., DOBBELSTEIN D., WINKLER C., HAAS G., RUKZIO E.: Facetouch: Enabling touch interaction in display fixed uis for mobile virtual reality. In *Proc. of the 29th Annual Symposium on User Interface Software and Technology* (2016), UIST '16, pp. 49–60. 2

[Gel06] GELLER T.: Interactive tabletop exhibits in museums and galleries. *IEEE Computer Graphics & Applications 26*, 5 (2006), 6–11. 2

[GSFR17] GUGENHEIMER J., STEMASOV E., FROMMEL J., RUKZIO E.: Sharevr: Enabling co-located experiences for virtual reality between hmd and non-hmd users. In *Proc. of the 2017 CHI Conference on Human Factors in Computing Systems* (2017), CHI '17, pp. 4021–4033. 3

[HBCdlR11] HACHET M., BOSSAVIT B., COHÉ A., DE LA RIVIÈRE J.-B.: Toucheo: Multitouch and stereo combined in a seamless workspace. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology* (2011), UIST '11, pp. 587–592. 2

[HBGA03] HUA H., BROWN L. D., GAO C., AHUJA N.: A new collaborative infrastructure: Scape. In *Proceedings of the IEEE Virtual Reality 2003* (2003), VR '03. 3

[HMDR08] HORNECKER E., MARSHALL P., DALTON N. S., ROGERS Y.: Collaboration and interference: Awareness with mice or touch input. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (2008), CSCW '08, pp. 167–176. 2

[Hor08] HORNECKER E.: "i don't understand it either, but it is cool" - visitor interactions with a multi-touch table in a museum. In *2008 3rd IEEE International Workshop on Horizontal Interactive Human Computer Systems* (2008), pp. 113–120. 2

[ISS*15] IBAYASHI H., SUGIURA Y., SAKAMOTO D., MIYATA N., TADA M., OKUMA T., KURATA T., MOCHIMARU M., IGARASHI T.: Dollhouse vr: A multi-view, multi-user collaborative design workspace with vr technology. In *SIGGRAPH Asia 2015 Emerging Technologies* (2015), SA '15, pp. 8:1–8:2. 3

[KGP*12] KLEIN T., GUÃL'NIAT F., PASTUR L., VERNIER F., ISENBERG T.: A Design Study of Direct-Touch Interaction for Exploratory 3D Scientific Visualization. *Computer Graphics Forum* (2012). 2

[LIM*15] LOPES P., ION A., MÜLLER W., HOFFMANN D., JONELL P., BAUDISCH P.: Proprioceptive interaction. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (2015), CHI EA '15, pp. 175–175. 2

[LRF*11] LUNDSTRÖM C., RYDELL T., FORSELL C., PERSSON A., YNNERMAN A.: Multi-touch table system for medical visualization: Application to orthopedic surgery planning. *Transactions on Visualization and Computer Graphics 17*, 12 (2011), 1775–1784. 2

[MRB*14] MARTON F., RODRIGUEZ M. B., BETTIO F., AGUS M., VILLANUEVA A. J., GOBBETTI E.: Isocam: Interactive visual exploration of massive cultural heritage models on large projection setups. *J. Comput. Cult. Herit. 7*, 2 (2014), 12:1–12:24. 2

[OI12] OSHITA M., ISHIKAWA H.: Gamepad vs. touchscreen: A comparison of action selection interfaces in computer games. In *Proceedings of the Workshop at SIGGRAPH Asia* (2012), WASA '12, pp. 27–31. 2

[PCKS00] PLETINCKX D., CALLEBAUT D., KILLEBREW A. E., SILBERMAN N. A.: Virtual-reality heritage presentation at ename. *IEEE MultiMedia 7*, 2 (2000), 45–48. 3

[PI99] POUPYREV I., ICHIKAWA T.: Manipulating objects in virtual worlds: Categorization and empirical evaluation of interaction techniques. *Journal of Visual Lang. & Computing 10*, 1 (1999), 19–35. 3

[RAB*16] RODRÍGUEZ M. B., AGUS M., BETTIO F., MARTON F., GOBBETTI E.: Digital mont’e prama: Exploring large collections of detailed 3d models of sculptures. *J. Comput. Cult. Herit. 9*, 4 (Sept. 2016), 18:1–18:23. 2

[SBJ*14] SUNDÉN E., BOCK A., JÖNSSON D., YNNERMAN A., ROPINSKI T.: Interaction Techniques as a Communication Channel when Presenting 3D Visualizations. In *IEEE VIS International Workshop on 3DVis* (2014), IEEE Digital Library. 2

[SKSK09] SAKURAI S., KITAMURA Y., SUBRAMANIAN S., KISHINO F.: A visibility control system for collaborative digital table. *Personal Ubiquitous Comput. 13*, 8 (Nov. 2009), 619–632. 3

[SPT06] STAFFORD A., PIEKARSKI W., THOMAS B.: Implementation of god-like interaction techniques for supporting collaboration between outdoor ar and indoor tabletop users. In *Proceedings of the 5th IEEE and ACM International Symposium on Mixed and Augmented Reality* (2006), ISMAR '06, pp. 165–172. 3

[WL14] WANG J., LINDEMAN R.: Coordinated 3d interaction in tablet- and hmd-based hybrid virtual environments. In *Proc. of the 2Nd ACM Symposium on Spatial User Interaction* (2014), SUI '14, pp. 70–79. 2

[WL15] WANG J., LINDEMAN R. W.: Object impersonation: Towards effective interaction in tablet- and hmd-based hybrid virtual environments. In *2015 IEEE Virtual Reality (VR)* (2015), pp. 111–118. 4

[WOFK13] WEBEL S., OLBRICH M., FRANKE T., KEIL J.: Immersive experience of current and ancient reconstructed cultural attractions. In *2013 Digital Heritage International Congress (DigitalHeritage)* (2013), vol. 1, pp. 395–398. 3

[WWWC04] WOJCIECHOWSKI R., WALCZAK K., WHITE M., CELLARY W.: Building virtual and augmented reality museum exhibitions. In *Proceedings of the Ninth International Conference on 3D Web Technology* (2004), Web3D '04, pp. 135–144. 3

[YRA*16] YNNERMAN A., RYDELL T., ANTOINE D., HUGHES D., PERSSON A., LJUNG P.: Interactive visualization of 3D scanned mummies at public venues. *Communications of the ACM 59*, 12 (2016), 72–81. 2

[YSI*10] YU L., SVETACHOV P., ISENBERG P., EVERTS M. H., ISENBERG T.: Fi3d: Direct-touch interaction for the exploration of 3d scientific visualization spaces. *IEEE Transactions on Visualization and Computer Graphics 16*, 6 (2010), 1613–1622. 2