Remote Collaboration With Mixed Reality Displays: How Shared Virtual Landmarks Facilitate Spatial Referencing

Jens Müller
HCI Group
University of Konstanz
jens.mueller@uni.kn

Roman Rädle
DDIS
Aarhus University
roman.raedle@cc.au.dk

Harald Reiterer
HCI Group
University of Konstanz
harald.reiterer@uni.kn

ABSTRACT
HCI research has demonstrated Mixed Reality (MR) as being beneficial for co-located collaborative work. For remote collaboration, however, the collaborators' visual contexts do not coincide due to their individual physical environments. The problem becomes apparent when collaborators refer to physical landmarks in their individual environments to guide each other's attention. In an experimental study with 16 dyads, we investigated how the provisioning of shared virtual landmarks (SVLs) influences communication behavior and user experience. A quantitative analysis revealed that participants used significantly less ambiguous spatial expressions and reported an improved user experience when SVLs were provided. Based on these findings and a qualitative video analysis we provide implications for the design of MRs to facilitate remote collaboration.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g., HCI): User Interfaces.

Author Keywords
Mixed Reality; remote collaboration; virtual landmarks.

INTRODUCTION
Mixed Reality (MR) describes the "merging of real and virtual worlds" on a display [23]. MR displays can create the illusion of virtual objects being situated in the user's physical environment. MR has been proposed for a variety of application domains such as architecture [20], education [6, 11], computer-aided instruction [12], medical visualizations [1] as well as a tool for computer-supported cooperative work (CSCW) [15, 27, 19, 5, 3, 28, 30, 25]. Recent technological advancements show that this belief is not far from reality with technologies like Microsoft HoloLens [22] and Google's Project Tango Tablet [10]. They are about to find their way into our everyday lives and will provide novel collaborative experiences such as MR remote assistance (e.g., [22]). Despite their potentials as collaborative interfaces, research on how MR interfaces can be used to enhance face-to-face and remote collaboration has not been widely investigated [4]. Especially the design of distributed groupware systems have to account for sufficient information resources to keep the collaborators aware of each other's actions and thereby maintain "the fluidity and naturalness" of face-to-face collaboration [16]. This work addresses this research area by focusing on remote collaboration with MR displays and one of its inherent issues: collaborative spatial referencing with different visual contexts (Figure 1).

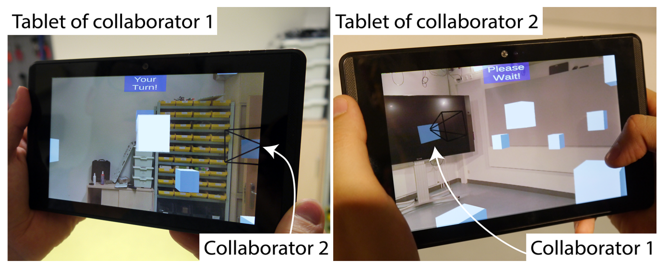

Figure 1. Remote collaboration with MR displays. Virtual work objects (cubes) are integrated into collaborators' physical environment. Physical objects can not serve as reference objects to guide each other's attention to specific work objects as they are individual to each collaborator.

Collaborative activities require group members to coordinate their actions to prevent from a potential "process loss" [31]. For that reason, Benford et al. suggest the provisioning of a "persistent context" for successful group activities [3]. Studies (e.g., [5, 13, 24]) show that such a "shared visual context" [13] can positively influence group conversation and help to establish a mutual understanding of the shared workspace. This becomes apparent when remote collaborators use spatial references to guide each other's attention to particular work objects. For such *spatial referencing*, visually outstanding features in the environment–so-called landmarks–can play a vital role [17] as they can serve as "spatial anchors" by which locations of other objects can be expressed [26, 29]. This, however, implies that for tasks that contain similarly looking work objects (e.g., work notes in affinity diagramming or atoms in molecular modeling), the work objects themselves may not serve well as landmarks. Furthermore, and with respect to remote collaboration, successful spatial referencing assumes that the landmark that is used by the addresser is also visible by the addressee. With MR displays as tools for remote collaboration, however, the addresser may refer to physical landmarks within their individual environment. This can result in communication ambiguities [7] as the addresser's physical landmarks are not necessarily available in the addressee's physical environment (Figure 1).

CHI 2017, May 06–11, 2017, Denver, CO, USA.
© 2017 ACM. ISBN 978–1–4503–4655–9/17/05. . . ...$15.00
DOI: http://dx.doi.org/10.1145/3025453.3025717

Benford et al. [3] provide a classification to investigate trade-offs for the design of shared-spaces experiences. This classification describes the qualities of shared-space technologies in terms of two dimensions. First, *Transportation* is defined as "the extent to which a group of participants and objects leave behind their local space and enter into some new remote space in order to meet with others." Hence, the more transportation qualities the interface provides, the less significant the physical environment becomes. Second, and following the notion of MR as a continuum (Milgram et al. [23]), *Artificiality* is defined as "the extent to which a space is either synthetic or is based on the physical world. This spans the extremes from wholly synthetic to wholly physical environments." [3]

Concerning the identified issue of different visual contexts during remote collaboration with MR displays, we consider both aspects particularly relevant to investigate design trade-offs and their consequences on collaborative processes. We assume that increasing artificiality through the provisioning of shared virtual landmarks (SVLs, e.g., a virtual plant, Figure 2) also increases the shared visual context during remote collaboration and can thus positively influence collaborative processes. In this work, we address the following research question: *Does the provisioning of shared virtual landmarks–as a means to increase the shared visual context–positively influence remote collaboration with MR displays?*

HYPOTHESES

H1: SVLs influence participants' communication behavior. The provisioning of SVLs increases collaborators' shared visual context, which allows them to develop a better mutual understanding of their shared workspace. Also, collaborators can use the landmarks as "spatial anchors" to communicate spatial information, which enables them to identify the target objects clearly without ambiguity.

H2: SVLs improve user experience. Collaborators value the presence of SVLs, which results in an improved user experience.

EXPERIMENT

The study used a counterbalanced within-subjects design with the provisioning of shared virtual landmarks being the independent variable (see Figure 1 for the baseline condition, and Figure 2 for the SVL condition).

Study, Apparatus, and Task

The study took place in two rooms at our university department representing two distinct physical workspaces for the collaborators. As MR displays we used Project Tango Tablets [9]. To provide a communication channel during the task, we installed TeamSpeak 3 [14] on the tablets.

Similar to Müller et al. [24] we designed a collaborative version of the memory card game to evoke spatial referencing between collaborators. Unlike in Müller et al.'s experiment [24], collaborators were located in spatially distributed rooms. This poses different challenges in terms of the "perceptual mechanisms used to maintain awareness" [16] during collaborative spatial referencing. We distributed 20 virtual cubes in

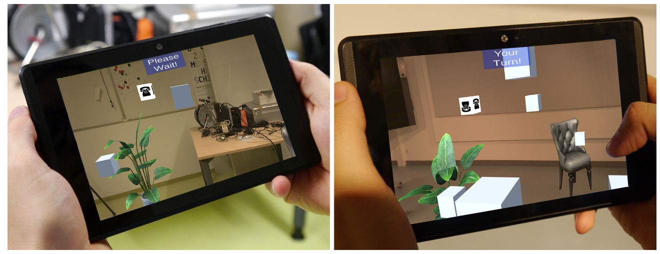

Figure 2. In addition to the work objects (cubes) several objects (e.g., a plant) are available and can serve the collaborators as SVLs in relation to which other work objects can be defined.

each room. The position of the collaborator's tablet was visualized as virtual viewing frustum (Figure 1). Each cube could be "uncovered" by touching its representation on the tablet screen. Cubes were textured with an icon which became visible in the uncovered state (Figure 2). There were 10 pairs of cubes being textured with the same icon. Icons were taken from the Wingdings font. Participants had to collaboratively find cubes with the same icon. In each turn, each collaborator was allowed to uncover one cube. Once collaborators found a match, the two associated cubes were removed from the MR environment, otherwise the two cubes turned into "covered" state after a delay of three seconds. Two video cameras–one in each room–recorded the study, audio was captured and recorded from TeamSpeak, and interactions (navigation and uncover events) were logged. The study prototype was implemented using Unity3D [32].

As SVLs we used objets that augment the physical environment, similar to Müller et al. [24]: an armchair, a bookshelf, a small potted plant, a potted tree, and a ceiling lamp. SVLs were placed in the shared 3D space in such a way that they naturally augmented the collaborators' physical environment.

DEPENDENT VARIABLES AND ANALYSIS

To investigate whether SVLs change *Communication Behavior* we analyzed the collaborators' expressions that they used for spatial referencing. Quantitative analysis of spatial expressions is based on video coding. We gained additional, qualitative findings that refer to participants' communication experiences in a concluding interview after participants had finished both conditions.

After completion of each study condition, we provided a customized questionnaire to assess *user experience*. With the first questionnaire item, we requested participants' *self assessment on how well they were able to communicate spatial information* with their partner (*"How do you assess your abilities to exchange spatial information?"* 10-point Likert scale). In the second part we assessed participants' sense of *Transportation*, using the sub-dimension *Social presence - Actor within medium (parasocial interaction)* of the Temple Presence Inventory [21]. In the concluding interview, participants indicated their favored condition (*Preference*) and reported their general experiences in the two conditions.

Study Procedure

Participants were welcomed and introduced to the study. Afterward, they were taken to different rooms by two examiners. In their associated room they were asked to fill out a demographic questionnaire. Then, participants were provided a training phase to familiarize themselves with the devices and the task. In this phase, no shared virtual landmarks were provided and a test set of symbols and coordinates was used. After approx. 3 min participants started with the study task in their assigned first study condition (approx. 10 min). Then, participants were asked to fill out the questionnaire on their user experiences. This procedure was repeated in the respective other condition. Afterwards, a concluding, semi-structured group interview on participants' preferences and experience was conducted by the two examiners. Each session took approx. 40 minutes.

Participants

We recruited 32 participants (20 female, 12 male) between 19-26 years of age (M = 23.08, SD = 1.71), forming 16 dyads. 29 participants were university students and 3 were employees.

Findings

Significance tests assume a p-value $< .05$. Non-parametric tests were used when the assumption of normal distribution was violated. Results are marked with the subscript $_B$ for the baseline condition (without SVLs) and with the subscript $_{SVL}$ when SVLs were provided.

Communication Behavior

We first synchronized video, audio, and interaction logs. We then took the synchronized videos from half of the sessions and analyzed for types of spatial expressions. A cluster analysis revealed a set of 6 categories:

- *Physical Object:* The addresser refers to a physical object in their individual environment to communicate the position of the target object (e.g., *"above the wastebasket"*.)
- *Deictic Speech:* The addresser does not explicitly refer to an object to communicate the position of the target object, which is why deictic expressions "cannot be fully understood by speech alone" [18] (e.g., *"over there"*, *"here"*).
- *Room:* The addresser uses features of the physical structure of their individual environment to communicate the position of the target object (e.g., *"in the corner"*, *"on the ground"*).
- *Person:* The addresser refers to either himself/herself (e.g., *"in front of me"*), or to the addressee (e.g., *"in front of you"*) or to both collaborators (e.g., *"in between of us"*).
- *Cube*: The addresser refers to an already uncovered cube to guide the addressee's attention to a nearby target object (*"the one behind the uncovered cube"*).
- *SVL:* The addresser refers to one of the shared virtual landmarks to specify the position of the target object (e.g., *"the cube above the armchair"*).

We then analyzed all videos for spatial expressions using the 6 categories as coding scheme. We determined the number of occurrences of each category in each condition per session. A Wilcoxon signed-ranks test did not reveal significant differences in the total number of spatial expressions ($z = -.664, p = .542, r = -.18$). In the SVL condition, however, participants used significantly less deictic expressions ($Mdn_B = 30.00$, $Mdn_{SVL} = 17.00$; $z = -2.200$, $p < .05$, $r = -.61$) and significantly more SVLs ($Mdn_B = 0.00$, $Mdn_{SVL} = 12.00$; $z = -3.061$, $p < .001$, $r = -.85$) (Figure 2).

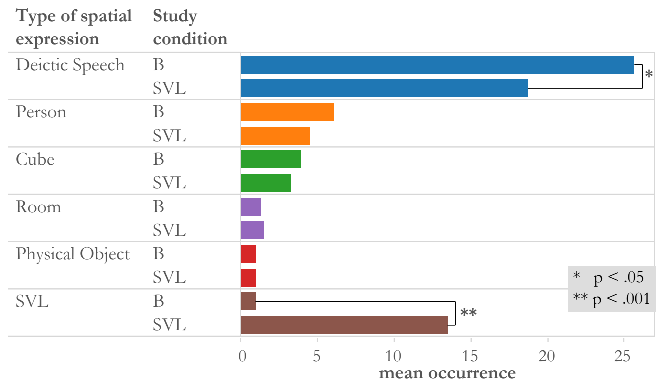

Figure 3. Mean occurrences of spatial expressions collaborators used to specify the position of the target cube.

User Experiences

A Wilcoxon signed-ranks test of users' perceived communication abilities (1 = very bad, 7 = very good) revealed that users assessed their abilities to communicate spatial information significantly higher when SVLs were provided. ($Mdn_B = 6.00$, $SVL_B = 6.00$, $z = -2.234$, $p < .05$, $r = -.39$).

Analysis of the Transportation items using the Wilcoxon signed-ranks test revealed that participants rated the item *How much did it seem as if you and the people you saw/heard both left the places where you were and went to a new place?* significantly higher when SVL were provided ($Mdn_B = 3.00$, $Mdn_{SVL} = 4.00$, $z = -2.104$, $p < .05$, $r = -.37$). There was no significant difference between the ratings of the question *How much did it seem as if you and the people you saw/heard were together in the same place?*

In the concluding interview, all participants (N = 32) favored the condition where SVLs were provided. As a reason, participants stated that the SVL provided them a universal reference system (n = 11, e.g., *"universal referencing options," "same room for both of us," "common orientation," "absolute references"*), a better orientation (n = 8, e.g., *"better orientation," "better orientation and more reference points"*), and better spatial memory capabilities (n = 3, e.g., *"easier to recall the cube positions," "better assignment of cubes"*). Participants did not indicate a specific SVL as being particularly outstanding or preferred.

Additional Findings

There was no significant difference in task completion time (TCTs) between baseline condition and landmarks condition, $t(15) = 1.133$, $p = 0.275$, $r = 0.28$.

We analyzed the videos by looking for conflict scenarios, reasons for conflicts, and participants' strategies to overcome them. Each conflict was annotated with a brief description of the current situation and associated, representative quotes from the collaborators. We identified 3 frequent conflict situations:

- *Addressee is unable to interpret a spatial expression:* This situation typically occurred due to either ambiguous, mostly deictic expressions or the use of physical landmarks. Dyads solved this either via several conversational turns or using a distinct SVL if they were available. Alternatively, collaborators positioned themselves in such a way that they could take the same perspective on the cubes.

- *Unawareness of collaborator's performed interactions:* This frequently happened in both conditions and became problematic as cubes would either disappear (in the case of a match) or as they would automatically turn into covered state. When SVLs were provided, the participant who performed the action on the cube could refer to it via a nearby SVL (e.g., *"I opened to one above the plant"*).
- *Cubes were overlooked:* In both conditions, collaborators sometimes missed some of the remaining cubes, especially towards the end of the task. Interestingly, conflict reasons and solving strategies differed between study conditions. When no SVLs were provided, dyads often did not realize the cubes that were positioned above their field of view (FOV), slightly above their heads until they started actively searching for the missing cubes. When SVLs were provided the SVLs (in this case the ceiling lamp) drew collaborators' attention above their natural FOV to the higher positioned cubes. But we also identified cases SVLs occluded collaborators' FOV. Again this required the collaborators to actively change their perspectives and search for the missing cubes.

DISCUSSION, LIMITATIONS, AND FUTURE DIRECTIONS

Confirming our hypothesis H1, SVLs changed collaborators' communication behavior. While the number of spatial expressions did not significantly differ between both conditions, the proportions of types of spatial expressions changed. Collaborators used significantly less deictic expressions when SVLs were provided. Thereby they could avoid ambiguities, misinterpretations, and longer conversational turns. Conversational turns were only analyzed in terms of conflict situations. The collaborative model for the process of reference [8] implies that efficiency of communication can be determined by the number of collaborators' conversational turns between initialization and mutual acceptance. Due to the complexity of natural conversation we were not able to clearly identify whether or not collaborators achieved mutual acceptance before they performed an action. For future studies, the study task should therefore contain a mechanism that asks the collaborators whether they had referred to the same cube after the uncover event.

Findings from user experiences and video observations confirm H2 and further stress the importance of SVLs: Even though there were no significant differences in TCT between the two conditions, SVLs were extensively used and the SVLs condition was favored by all participants. As the most frequently mentioned reason, they stated that the SVLs helped to establish a universal reference system which both collaborators could refer to. Likewise, conflict situations could be resolved more efficiently when SVLs were provided unless SVLs occluded some of the cubes. Furthermore, participants indicated that they felt as if they were transported to some other place when SVLs were provided. This indicates that the increase of artificiality via SVLs reduced the importance of the participants' physical context. Our analysis, however, did not reveal that collaborators felt as if they were transported into the same work space. One explanation could be that SVLs were not sufficiently outstanding. Thus, future research should focus on how to establish remote collaboration with MR displays that transports collaborators into the same space.

IMPLICATIONS FOR THE DESIGN

Based on these findings and a qualitative video analysis we provide implications for the design of MRs to facilitate remote collaboration.

- *Provide SVLs:* Based on our findings we suggest the provisioning of SVLs, as they reduced collaborators' non-shared, physical context, increased user experience and facilitated spatial referencing.
- *Position and Choice of SVLs:* Analysis of spatial expressions revealed that collaborators sometimes referred to their individual environment (e.g., *"in the corner of the room"*). Spatial references like these can become problematic when the sizes of the rooms differ significantly. In such cases we suggest using larger SVLs (like the shelf) to frame the physical 3D volume in which the work objects are positioned. Thereby SVLs can create a frame of reference. Furthermore, the application domain and its related work objects may determine the choice of SVLs and their positioning. In our experimental setting we positioned some cubes above collaborators' FOV. In such scenarios, SVLs (such as the ceiling lamp) can guide collaborators' attention to work objects that are above their FOV.
- *Make interactions visible:* We consider this an issue not particularly limited to our study setting but rather a general issue of remote MR collaboration. Future research is necessary to study techniques to overcome this issue (e.g., highlighting objects that are manipulated and providing a 3D adaption of the (2D) Halo [2] technique to visualize off-screen objects, collaborators, and events).
- *Provide the means to deactivate the SVLs:* While the provisioning of SVLs generally facilitated communication and improved user experience, they could also caused occlusion of work objects. Thus, each collaborator should individually be provided the means to deactivate the SVLs temporarily to foreground the work objects.

CONCLUSION

In this work we addressed the issue of different visual contexts during remote collaboration with MR displays. We proposed SVLs as a means to increase collaborators' shared visual context. Results of an experimental study show that SVLs positively influence communication behavior in the sense that they reduced the occurrence of ambiguous deictic expressions which could cause conflict situations. In addition, participants reported a significantly increased user experience and favored the SVL condition. Based on these findings and a qualitative video analysis, we provide implications for the design of MR environments, particularly for those where the virtual work objects are not suitable as landmarks. In addition, we identified future research directions to further facilitate remote collaboration with MR displays.

ACKNOWLEDGEMENTS

The work was supported by SmartAct. We also thank Matthias Kraus and Matthias Miller for their hands-on support.

REFERENCES

1. Michael Bajura, Henry Fuchs, and Ryutarou Ohbuchi. 1992. Merging Virtual Objects with the Real World: Seeing Ultrasound Imagery Within the Patient. In *Proceedings of the 19th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '92)*. ACM, New York, NY, USA, 203–210. DOI: http://dx.doi.org/10.1145/133994.134061
2. Patrick Baudisch and Ruth Rosenholtz. 2003. Halo: A Technique for Visualizing Off-screen Objects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '03)*. ACM, New York, NY, USA, 481–488. DOI: http://dx.doi.org/10.1145/642611.642695
3. Steve Benford, Chris Greenhalgh, Gail Reynard, Chris Brown, and Boriana Koleva. 1998. Understanding and Constructing Shared Spaces with Mixed-reality Boundaries. *ACM Trans. Comput.-Hum. Interact.* 5, 3 (Sept. 1998), 185–223. DOI: http://dx.doi.org/10.1145/292834.292836
4. Mark Billinghurst, Adrian Clark, and Gun Lee. 2015. A Survey of Augmented Reality. *Found. Trends Hum.-Comput. Interact.* 8, 2-3 (March 2015), 73–272. DOI:http://dx.doi.org/10.1561/1100000049
5. Mark Billinghurst and Hirokazu Kato. 1999. Collaborative Mixed Reality. In *International Symposium on Mixed Reality (MR '99)*.
6. Mark Billinghurst, Hirokazu Kato, and Ivan Poupyrev. 2001. The MagicBook: a transitional {AR} interface. *Computers Graphics* 25, 5 (2001), 745 – 753. DOI: http://dx.doi.org/10.1016/S0097-8493(01)00117-0 Mixed realities - beyond conventions.
7. Jeff Chastine and Ying Zhu. 2008. The Cost of Supporting References in Collaborative Augmented Reality. In *Proceedings of Graphics Interface 2008 (GI '08)*. Canadian Information Processing Society, Toronto, Ont., Canada, Canada, 275–282. http://dl.acm.org/citation.cfm?id=1375714.1375760
8. Herbert H. Clark and Deanna Wilkes-Gibbs. 1986. Referring as a Collaborative Process. *Cognition* 22, 1 (1986), 1–39. DOI: http://dx.doi.org/10.1016/0010-0277(86)90010-7
9. Google Developers. 2016a. Tango Tablet Development Kit User Guide. Website. (25 August 2016). Retrieved August 31, 2016 from https://developers.google.com/tango/hardware/tablet.
10. Google Developers. 2016b. What's New with Project Tango - Google I/O 2016. Video. (19 May 2016). Retrieved August 22, 2016 from https://www.youtube.com/watch?v=yvgPrZNp4So.
11. Andreas Dünser and Eva Hornecker. 2007. Lessons from an AR Book Study. In *Proceedings of the 1st International Conference on Tangible and Embedded Interaction (TEI '07)*. ACM, New York, NY, USA, 179–182. DOI: http://dx.doi.org/10.1145/1226969.1227006
12. Steven Feiner, Blair Macintyre, and Dorée Seligmann. 1993. Knowledge-based Augmented Reality. *Commun. ACM* 36, 7 (July 1993), 53–62. DOI: http://dx.doi.org/10.1145/159544.159587
13. Susan R. Fussell, Robert E. Kraut, and Jane Siegel. 2000. Coordination of Communication: Effects of Shared Visual Context on Collaborative Work. In *Proceedings of the 2000 ACM Conference on Computer Supported Cooperative Work (CSCW '00)*. ACM, New York, NY, USA, 21–30. DOI: http://dx.doi.org/10.1145/358916.358947
14. TeamSpeak Systems GmbH. 2016. Welcome to TeamSpeak. Website. (2016). Retrieved September 13, 2016 from https://www.teamspeak.com/.
15. Raphael Grasset, Philip Lamb, and Mark Billinghurst. 2005. Evaluation of Mixed-Space Collaboration. In *Proceedings of the 4th IEEE/ACM International Symposium on Mixed and Augmented Reality (ISMAR '05)*. IEEE Computer Society, Washington, DC, USA, 90–99. DOI:http://dx.doi.org/10.1109/ISMAR.2005.30
16. Carl Gutwin and Saul Greenberg. 2002. A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Computer Supported Cooperative Work (CSCW)* 11, 3 (2002), 411–446. DOI: http://dx.doi.org/10.1023/A:1021271517844
17. Rob Ingram and Steve Benford. 1995. Legibility enhancement for information visualisation. In *Visualization, 1995. Visualization '95. Proceedings., IEEE Conference on*. 209–216, 454. DOI: http://dx.doi.org/10.1109/VISUAL.1995.480814
18. Kiyoshi Kiyokawa, Mark Billinghurst, Sohan E. Hayes, Arnab Gupta, Yuki Sannohe, and Hirokazu Kato. 2002. Communication Behaviors of Co-Located Users in Collaborative AR Interfaces. In *Proceedings of the 1st International Symposium on Mixed and Augmented Reality (ISMAR '02)*. IEEE Computer Society, Washington, DC, USA, 135–144. http://dl.acm.org/citation.cfm?id=850976.854962
19. Kiyoshi Kiyokawa, Haruo Takemura, and Naokazu Yokoya. 2000. SeamlessDesign for 3D Object Creation. *IEEE MultiMedia* 7, 1 (Jan. 2000), 22–33. DOI: http://dx.doi.org/10.1109/93.839308
20. Gun A. Lee, Andreas Dunser, Seungwon Kim, and Mark Billinghurst. 2012. CityViewAR: A mobile outdoor AR application for city visualization. *2013 IEEE International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH)* 0 (2012), 57–64. DOI: http://dx.doi.org/10.1109/ISMAR-AMH.2012.6483989
21. Matthew Lombard, Theresa. B. Ditton, and Lisa Weinstein. 2009. Measuring Presence: The Temple Presence Inventory. In *Proceedings of the 12th Annual International Workshop on Presence*.

22. Microsoft. 2015. Microsoft HoloLens - Transform your world with holograms. Video. (21 January 2015). Retrieved August 22, 2016 from https://www.youtube.com/watch?v=aThCr0PsyuA.

23. Paul Milgram and Fumio Kishino. 1994. A Taxonomy of Mixed Reality Visual Displays. *IEICE Trans. Information Systems* E77-D, 12 (1994), 1321–1329.

24. Jens Müller, Roman Rädle, and Harald Reiterer. 2016. Virtual Objects As Spatial Cues in Collaborative Mixed Reality Environments: How They Shape Communication Behavior and User Task Load. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 1245–1249. DOI: http://dx.doi.org/10.1145/2858036.2858043

25. Gerhard Reitmayr and Dieter Schmalstieg. 2004. Collaborative Augmented Reality for Outdoor Navigation and Information Browsing. In *Proceedings of the Second Symposium on Location Based Services and TeleCartography*. TU Wien, 53–62. http://publik.tuwien.ac.at/files/PubDat_137965.pdf

26. Joey Scarr, Andy Cockburn, and Carl Gutwin. 2013. Supporting and Exploiting Spatial Memory in User Interfaces. *Foundations and Trends in Human-Computer Interaction* 6, 1 (2013), 1–84. DOI: http://dx.doi.org/10.1561/1100000046

27. Dieter Schmalstieg, Anton Fuhrmann, Gerd Hesina, Zsolt Szalavári, L. Miguel Encarnaçäo, Michael Gervautz, and Werner Purgathofer. 2002. The Studierstube Augmented Reality Project. *Presence: Teleoper. Virtual Environ.* 11, 1 (2002), 33–54. DOI: http://dx.doi.org/10.1162/105474602317343640

28. Rajinder S. Sodhi, Brett R. Jones, David Forsyth, Brian P. Bailey, and Giuliano Maciocci. 2013. BeThere: 3D Mobile Collaboration with Spatial Input. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 179–188. DOI: http://dx.doi.org/10.1145/2470654.2470679

29. Molly E. Sorrows and Stephen C. Hirtle. 1999. The nature of landmarks for real and electronic spaces. In *Spatial information theory - Cognitive and computational foundations of geographic information science*, Christian Freksa and David M. Mark (Eds.). Springer, Berlin, 37–50. DOI: http://dx.doi.org/10.1007/3-540-48384-5_3

30. Aaron Stafford, Wayne Piekarski, and Bruce H. Thomas. 2006. Implementation of god-like interaction techniques for supporting collaboration between outdoor AR and indoor tabletop users. In *2006 IEEE/ACM International Symposium on Mixed and Augmented Reality*. 165–172. DOI: http://dx.doi.org/10.1109/ISMAR.2006.297809

31. Ivan Dale Steiner. 1972. *Group Process and Productivity*. Academic Press.

32. Unity Technologie. 2016. Unity - Game Engine. Website. (2016). Retrieved September 12, 2016 from https://unity3d.com/.