Everyday Proxy Objects for Virtual Reality

Florian Daiber
florian.daiber@dfki.de
German Research Center for Artificial Intelligence (DFKI)
Saarbrücken, Germany

Donald Degraen
donald.degraen@dfki.de
German Research Center for Artificial Intelligence (DFKI)
Saarbrücken, Germany

André Zenner
andre.zenner@dfki.de
German Research Center for Artificial Intelligence (DFKI)
Saarbrücken, Germany

Tanja Döring
tanja.doering@uni-bremen.de
University of Bremen
Bremen, Germany

Frank Steinicke
steinicke@informatik.uni-hamburg.de
Universität Hamburg
Hamburg, Germany

Oscar Javier Ariza Núñez
ariza@informatik.uni-hamburg.de
Universität Hamburg
Hamburg, Germany

Adalberto L. Simeone
adalberto.simeone@kuleuven.be
Department of Computer Science, KU Leuven
Heverlee, Leuven, Belgium

Figure 1: By understanding the composition and availability of the real world objects available to a user while in VR, such as the objects on the table in this example, they could serve as ad-hoc props to provide multi-sensory feedback and enrich interactions.

ABSTRACT

Immersive virtual experiences are becoming ubiquitous in our daily lives. Besides visual and auditory feedback, other senses like haptics, smell and taste can enhance immersion in virtual environments. Most solutions presented in the past require specialized hardware to provide appropriate feedback. To mitigate this need, researchers conceptualized approaches leveraging everyday physical objects as proxies instead. Transferring these approaches to varying physical environments and conditions, however, poses significant challenges to a variety of disciplines such as HCI, VR, haptics, tracking, perceptual science, design, etc. This workshop will explore the integration of everyday items for multi-sensory feedback in virtual experiences and sets course for respective future research endeavors. Since the community still seems to lack a cohesive agenda for advancing this

CHI '21 Extended Abstracts, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8095-9/21/05.
https://doi.org/10.1145/3411763.3441343

domain, the goal of this workshop is to bring together individuals interested in everyday proxy objects to review past work, build a unifying research agenda, share ongoing work, and encourage collaboration.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **Virtual reality**; **Interaction design process and methods**; *Haptic devices*; *Ubiquitous and mobile devices.*

KEYWORDS

Virtual reality; substitutional reality; multi-sensory feedback; proxies; immersion; everyday objects.

ACM Reference Format:
Florian Daiber, Donald Degraen, André Zenner, Tanja Döring, Frank Steinicke, Oscar Javier Ariza Núñez, and Adalberto L. Simeone. 2021. Everyday Proxy Objects for Virtual Reality. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '21 Extended Abstracts), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3411763.3441343

1 INTRODUCTION

Through advances in display technology, tracking and computing performance, we approach a future where immersive virtual experiences are aspects of our everyday lives. For basic immersion, visual and auditory stimulation is commonly provided by means of head-mounted displays (HMDs) and headphones, sufficient for passive applications in which the user primarily observes the virtual scene. As VR applications become increasingly interactive, however, the importance of involving additional senses increases.

Being able to sense virtual objects and interactions, e.g. through tactile sensations, has been shown to enhance VR experiences in crucial ways [14, 27] - motivating researchers and practitioners to explore ways to integrate immersive haptic feedback to VR. The research community could observe different solutions emerge and a great amount of research effort has focused on developing specialized hardware, such as haptic VR controllers [2, 11, 26–28], or even more complex feedback systems [1]. Such systems, however, require the user to be in possession of specialized hardware - resulting in additional investments for the user and complex physical setups.

To lower the technical hurdle to immersive virtual experiences, researchers conceptualized approaches such as *passive haptics* [14] and *substitutional reality* [21, 23]. These approaches aim to leverage the physicality of the real environment to provide haptic sensations by utilizing everyday physical items as haptic proxies for virtual objects. These concepts aim to mitigate the need for specialized haptic hardware while still promising rich sensations in VR.

The utilization of everyday items that are likely to be found in different contexts, such as e.g., smartphones, books, paper, flowers, food, and alike, as proxies for virtual objects in VR, is an inherently multidisciplinary challenge. For seamless and immersive interaction with everyday objects in VR, research in disciplines such as HCI, VR/MR/AR, haptics, tracking, perceptual science, design, and more has to be combined. However, up to now, the research communities still lack a cohesive research agenda for advancing this domain.

Figure 2: A great amount of past research efforts have concentrated on the development of specialized hardware, such as the haptic VR controllers *Shifty* [27] and *Drag:on* [28].

This workshop aims to pave the path towards such a unified research agenda by inviting researchers and practitioners from all the related fields to jointly explore the potential for everyday objects to serve as multi-sensory proxies for virtual objects, scenes and interactions. Besides collecting the current state-of-the-art in this domain from different perspectives, the workshop fosters discussions about potential solutions to technical challenges and classifications of everyday items suitable to serve as props and their capabilities to provide haptic, olfactory and gustatory feedback.

Projecting existing active sensory feedback technologies in the future, the workshop further explores and discusses to which extent everyday objects should be able to produce active feedback, such as through vibrators, electrical stimulators, vaporizers etc. Some objects provide active multimodal feedback by themselves (e.g., auditory and vibrotactile feedback in a cellphone), or such type of feedback could be added to the object in the shape of small and attachable electronic modules, able to enrich a real-world object with multi-sensory properties to provide immersive sensations when used as VR proxies [17–19].

Finally, the workshop will focus the discussion on practical implications, emerging research topics and applications. To achieve these goals, the workshop is conceptually split in two parts. In the first part, the workshop topic and central theme is summarized by established experts in the domains of substitutional reality, interaction with props in virtual environments, and 3D interaction. The introductory talks are followed by a concise summary of the participants' relevant previous or ongoing related work. In the second part, the workshop topics are discussed in groups, driven by hands-on brainstorming sessions with tangible examples of everyday objects provided by the workshop organizers. The workshop aims to encourage the exchange of research and application ideas as participants will form interdisciplinary groups and cooperatively develop ideas on how to integrate example objects in different application scenarios such as games, sports, virtual meetings, simulations, training, education or data visualization. To conclude the event, the results will be discussed in the plenum at the end of the day.

2 BACKGROUND

In the last years VR-related research is getting more and more popular in CHI and CHI-related venues. To strengthen the feeling of presence experienced by users, recent research efforts have explored various approaches to involve a multitude of senses into the experience. Besides visual and auditory feedback, interactive virtual experiences demand also the haptic sensation as users expect appropriate tactile and kinesthetic cues. Techniques to provide haptic feedback in VR can be classified as active, passive and mixed approaches [27]. While active haptic feedback leverages computer-controlled actuators to simulate and convey forces to the user [17, 24], passive haptic approaches rely on physical props that represent virtual objects to provide haptic sensations [14]. Mixed approaches aim to combine the advantages of both concepts by combining the idea of props and actuation [26–28]. In this context, for example, researchers and practitioners designed and explored handheld VR controllers providing different haptic sensations [2, 11, 26–28]. These, however, represent specialized devices targeting specific applications and effects.

In this workshop, we aim to extend these concepts and to explore how everyday objects that are likely to be found in the surroundings of the user can be utilized to provide multi-sensory experiences. In accordance with classifications such as passive haptic feedback [14], we aim to discuss how daily objects such as smartphones, plants, food, books, and alike can serve as proxies for different virtual objects in various application domains. In this context, Simeone et al. [23] coined the term *Substitutional Reality*. Some of the related work has explored the use of everyday objects in specific application areas [8, 13, 16, 20, 23] or for specific groups of individuals [10, 29].

Community building efforts have also been undertaken in this and related areas, such as with "The 3rd Dimension of CHI (3DCHI): Touching and Designing 3D User Interfaces" Workshop [25], the "Interactive Surfaces for Interaction with Stereoscopic 3D (ISIS3D)" Tutorial and Workshop at ITS 2013 [3], the "Workshop on Everyday Virtual Reality (WEVR)" series[1], the "Challenges Using Head-Mounted Displays in Shared and Social Spaces (SHMD)" Workshop [9], the Workshop on Cross-Reality (XR) Interaction [22], and the first attempt to organize the EPO4VR Workshop at CHI 2020 [4]. However, none of them specifically targeted the use of everyday objects as multi-sensory proxies in VR with the objective to bring together the many involved disciplines in an interactive discussion. Moreover, many researchers and practitioners are still unaware of others working in this area, parallel developments and of the work they are doing. We hope that this workshop will be an event in which the community lays a foundation for future work and gatherings.

3 WORKSHOP TOPICS

To guide discussions and structure ideas, we frame three main topics regarding the use of everyday objects in immersive virtual environments.

[1] https://wevr.adalsimeone.me

Workshop Schedule	
14:00	Welcome & Introduction
14:15	Keynote Talk
15:00	Coffee Break
15:10	Lightning Talks Part 1
	Participants present their work and interests (5-10 min).
15:40	Coffee Break
15:50	Lightning Talks Part 2
	Participants present their work and interests (5-10 min).
16:20	Coffee Break
16:30	Breakout Sessions
	Participants discuss topic aspects in smaller groups.
17:00	Coffee Break
17:10	Group Discussion
17:50	Conclusion & Wrap-up

Table 1: Workshop Schedule

3.1 Leveraging everyday objects for multi-sensory VR

What is the current state-of-the-art for integrating everyday objects in VR [12]? How can research extend existing techniques for multi-sensory feedback by considering real-world, everyday objects for integration [21]? How can these objects be used to support immersive virtual experiences?

3.2 Classification of everyday objects for VR proxies

How can everyday objects suitable to serve as multi-sensory proxies be classified, e.g. by means of a taxonomy [23]? What are the properties and capabilities of different classes of everyday objects?

3.3 Practical implications of using everyday objects in VR

What degree of passiveness or activeness does an object require to be integrated successfully [27]? Which requirements does the integration of everyday objects pose to a VR system (e.g., tracking, environment, energy, etc.)? Which application areas are suitable for these objects?

4 WORKSHOP GOALS

We put forward the following goals as an output for our workshop.

4.1 Community Building

We will build on previous efforts in forming a community consisting of researchers and practitioners from different fields around this research theme. We will invite past attendees to closely related events and authors of on-topic published papers. Connections and collaborations will be encouraged as individuals learn about others with similar research interests and goals. The workshop organizers have organized many of the past closely-related events.

4.2 Establish Research Directions and Goals

Sharing of individual and group research will allow for a mapping of the design space related to everyday proxy objects for VR. This includes understanding both which areas of this space have been explored through existing work and which areas remain largely unexplored. This will help us as a community to establish clear research directions, questions, and goals moving forward.

4.3 Plan for Fostering a Research Community

A final and very important goal for the workshop will be to unite around a plan to foster both the growth of the community and the growth of the research discipline of everyday objects for VR. This is partially fulfilled by the other goals, but also requires careful planning for future events within the community, either standalone or in conjunction with other HCI venues.

5 PRE-WORKSHOP PLANS

Participants will be recruited by distributing a CFP in all relevant communities. The CFP will be announced on various mailing lists, e.g., ACM, CHI-announcements, and through social media, e.g., Facebook, Twitter, Instagram. The organizers have access to the necessary email lists and social media groups. Additionally, we will directly contact researchers and practitioners likely to be interested in the workshop and will write invitations to relevant institutions and research labs.

Before the workshop, all position papers will be reviewed and rated using a juried process managed by the workshop organisers. Authors of accepted papers will be invited to participate in the workshop and will have the possibility to have their contribution hosted on the workshop website.

6 WORKSHOP STRUCTURE

Similar to the main conference, the workshop will take place virtually. We aim to balance community building and group discussions to frame a long term research agenda. The program is divided into an introduction session followed by group breakout discussions to provide a framework for creativeness and support meaningful participant interactions.

In the first part of this workshop, the current state of research is summarized by established experts in the domains of substitutional reality, interaction with props in virtual environments, and 3D user interaction, followed by an introduction of the participants' relevant work. Here, the organizers will start with an introduction and welcome session followed by one or more invited keynotes. After a short coffee break, participants will introduce themselves and briefly present their position paper to frame their ongoing work and research interests. This session will be split up into multiple parts separated by short breaks to lower participants' workload.

In the second part of the workshop, we will interactively develop concepts for integrating various everyday objects in virtual experiences using creative methods known from design thinking and group discussions. Participants will form groups, each of which will jointly discuss the workshop topics and related questions outlined in section 3. To spark discussions, each group will also cooperatively develop ideas on how to integrate example objects. The group discussions are followed by each group presenting a summary of their discussion together with interpretations of integrating their object in a virtual environment with one of the organizers taking notes. The presentations serve as insights to frame a research agenda for the community. The notes will become the first draft of the workshop report.

The main session of the workshop will take place using an online conferencing platform such as Mozilla Hubs or Zoom. For each group discussion, one of the organizers will arrange and setup a virtual breakout room, including a collaborative online workspace such as Miro[2] or Mural[3] to facilitate discussions. An overview of our workshop schedule is shown in Table 1. Depending on the amount of participants, the lightning talks can be split up into more sessions. We are planing for an afternoon workshop hosted in Berlin, Germany (e.g. 3pm CET), i.e. afternoon in European time zones, morning in American time zones, and evening in East Asian time zones. However, to accommodate for the difference in time zones, we propose to discuss and agree on a starting time with all participants.

7 POST-WORKSHOP PLANS

Through the workshop discussions, a report will serve as the primary tangible artifact of the workshop's outcome. The produced report will synthesize the results of the group discussions and will structure them according to the workshop topics outlined above. The organizers will take the lead in creating the report on a shared document editing service, such as Google docs. Afterwards, workshop attendees will be invited to participate in the expansion and revision of the document to ensure completeness. All results will be made available on the workshop website.

Additionally, participants will be invited to contribute to a paper which will detail the identified research challenges. We plan to outline a special issue for a journal, e.g., ToCHI, and invite participants to submit an extended version of their workshop papers.

Based on the workshop outcome, the organizers aim to foster collaboration between participants by setting up a communication platform, e.g., a Slack or Facebook group, such that participants can be supported in their planned work.

8 ORGANIZERS

This workshop will be organized by an interdisciplinary team of researchers actively working in the field of Virtual Reality experiences.

Florian Daiber is a post-doctoral researcher at the German Research Center for Artificial Intelligence (DFKI). His work involves 3D user interfaces and ubiquitous sports technologies particularly in the context of running and rock climbing. He co-organized the ISIS3D Workshop and Tutorial [3], the UbiMount workshops [5], the HCI Outdoors Workshop [15] and the XR Workshop [22].

Website: https://umtl.cs.uni-saarland.de/people/dr.-florian-daiber.html

Donald Degraen is a PhD candidate at Saarland University, Germany. His ongoing work explores how material perception in

[2] An Online Visual Collaboration Platform for Teamwork | Miro - https://miro.com/
[3] MURAL is a digital workspace for visual collaboration - https://www.mural.co/

immersive virtual environments can be enhanced using passive haptic feedback [6, 7]. As an initial approach, he investigated the influence of hair-like structures on the perception of roughness and hardness.

Website: https://www.donalddegraen.com

André Zenner is a PhD candidate at Saarland University, Germany. His research focus lies on techniques overcoming the drawbacks of passive haptics for VR by leveraging physical manipulations of the props (i.e., dynamic passive haptics) and virtual manipulations of user interactions (e.g., through hand redirection). In this context, he explored concepts for weight-shifting VR controllers like *Shifty* and presented the air resistance changing *Drag:on* controller at CHI 2019.

Website: https://umtl.cs.uni-saarland.de/people/andre-zenner.html

Tanja Döring is a post-doctoral researcher in the Digital Media Lab at the University of Bremen, Germany. Her research focuses on human-computer interaction and materiality, digital fabrication and novel interaction techniques including tangible and gestural interaction in augmented and virtual reality.

Website: https://www.uni-bremen.de/dmlab-1/team/dr-ing-tanja-doering

Frank Steinicke is a professor for Human-Computer Interaction at the Department of Informatics at the University of Hamburg. His research is driven by understanding the human perceptual, cognitive and motor abilities and limitations in order to reform the interaction as well as the experience in computer-mediated realities. He co-organized the *SocialHMDs* Workshop [9].

Website: https://www.inf.uni-hamburg.de/en/inst/ab/hci/people/steinicke.html

Oscar Javier Ariza Núñez is a a PhD candidate at the University of Hamburg, Germany. His research is focused on the development and evaluation of wearable haptic technology for 3D interaction techniques, dealing with multimodal active feedback to provide proximity-based and guidance cues.

Website: https://www.inf.uni-hamburg.de/en/inst/ab/hci/people/ariza.html

Adalberto L. Simeone is an Assistant Professor in the Department of Computer Science at the KU Leuven. His research lies in the intersection of 3D interaction and virtual reality with Human-Computer Interaction. He is motivated by a deep interest in making the technologies supporting the fruition of 3D contents more accessible by everyone. He organized the *WEVR* Workshops and the XR Workshop [22].

Website: https://www.adalsimeone.me

9 CALL FOR PARTICIPATION

The workshop on Everyday Proxy Objects for VR will explore the integration of everyday items for multi-sensory virtual experiences and sets course for respective future research endeavors. We welcome researchers and practitioners who have experience with or interest in using everyday objects as proxies for virtual objects, scenes or interactions in VR. Relevant topics might include, but are not limited to virtual, mixed and substitutional reality, tangible and everyday objects, multi-sensory devices and proxies, immersion and perception of everyday proxy objects.

** Important Dates **
Submission Deadline: February 21th, 2021
Notification: February 28th, 2021

To apply for the workshop, we invite submissions of position papers in the SIGCHI Extended Abstract format with a maximum length of 4 pages (not including bibliography). Position papers should address either previous work or future planned work in the scope of integrating everyday objects in immersive virtual experiences. Each participant will have 5 minutes for an oral presentation of their work. Please see the workshop website for details. Position papers will be reviewed by the workshop organizers. Participants will be selected according to the suitability of their research to contribute to the workshop outcome or the relevance of their workshop position paper. Upon acceptance, at least one author of each accepted paper must attend the workshop. All participants must register for both the workshop and for at least one day of the conference.

For more information and submitting your contributions, please visit: http://epo4vr.dfki.de/.

10 ACKNOWLEDGEMENTS

This work is partially funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - 425868555; 450247716.

REFERENCES

[1] Bruno Araujo, Ricardo Jota, Varun Perumal, Jia Xian Yao, Karan Singh, and Daniel Wigdor. 2016. Snake Charmer: Physically Enabling Virtual Objects. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction* (Eindhoven, Netherlands) *(TEI '16)*. Association for Computing Machinery, New York, NY, USA, 218–226. https://doi.org/10.1145/2839462.2839484

[2] Inrak Choi, Heather Culbertson, Mark R. Miller, Alex Olwal, and Sean Follmer. 2017. Grabity: A Wearable Haptic Interface for Simulating Weight and Grasping in Virtual Reality. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology* (Québec City, QC, Canada) *(UIST '17)*. Association for Computing Machinery, New York, NY, USA, 119–130. https://doi.org/10.1145/3126594.3126599

[3] Florian Daiber, Bruno Rodrigues De Araujo, Frank Steinicke, and Wolfgang Stuerzlinger. 2013. Interactive Surfaces for Interaction with Stereoscopic 3d (ISIS3D): Tutorial and Workshop at Its 2013. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces* (St. Andrews, Scotland, United Kingdom) *(ITS '13)*. Association for Computing Machinery, New York, NY, USA, 483–486. https://doi.org/10.1145/2512349.2512351

[4] Florian Daiber, Donald Degraen, André Zenner, Frank Steinicke, Oscar Javier Ariza Núñez, and Adalberto L. Simeone. 2020. Everyday Proxy Objects for Virtual Reality. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3334480.3375165

[5] Florian Daiber, Michael Jones, Frederik Wiehr, Keith Cheverst, Felix Kosmalla, and Jonna Häkkilä. 2017. UbiMount: 2nd Workshop on Ubiquitous Computing in the Mountains. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers* (Maui, Hawaii) *(UbiComp '17)*. Association for Computing Machinery, New York, NY, USA, 1022–1026. https://doi.org/10.1145/3123024.3124462

[6] Donald Degraen, Anna Reindl, Akhmajon Makhsadov, André Zenner, and Antonio Krüger. 2020. Envisioning Haptic Design for Immersive Virtual Environments. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference* (Eindhoven, Netherlands) *(DIS' 20 Companion)*. Association for Computing Machinery, New York, NY, USA, 287–291. https://doi.org/10.1145/3393914.3395870

[7] Donald Degraen, André Zenner, and Antonio Krüger. 2019. Enhancing Texture Perception in Virtual Reality Using 3D-Printed Hair Structures. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300479

[8] Anton Franzluebbers and Kyle Johnsen. 2018. Performance Benefits of High-Fidelity Passive Haptic Feedback in Virtual Reality Training. In *Proceedings of the Symposium on Spatial User Interaction* (Berlin, Germany) *(SUI '18)*. Association for Computing Machinery, New York, NY, USA, 16–24. https://doi.org/10.1145/3267782.3267790

[9] Jan Gugenheimer, Christian Mai, Mark McGill, Julie Williamson, Frank Steinicke, and Ken Perlin. 2019. Challenges Using Head-Mounted Displays in Shared and Social Spaces. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3290607.3299028

[10] A. Harrison, G. Derwent, A. Enticknap, F. D. Rose, and E. A. Attree. 2002. The role of virtual reality technology in the assessment and training of inexperienced powered wheelchair users. *Disability and Rehabilitation* 24, 11-12 (2002), 599–606. https://doi.org/10.1080/09638280110111360 arXiv:https://doi.org/10.1080/09638280110111360 PMID: 12182799.

[11] Seongkook Heo, Christina Chung, Geehyuk Lee, and Daniel Wigdor. 2018. Thor's Hammer: An Ungrounded Force Feedback Device Utilizing Propeller-Induced Propulsive Force. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3173574.3174099

[12] Anuruddha Hettiarachchi and Daniel Wigdor. 2016. Annexing Reality: Enabling Opportunistic Use of Everyday Objects as Tangible Proxies in Augmented Reality. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1957–1967. https://doi.org/10.1145/2858036.2858134

[13] Ken Hinckley, Randy Pausch, John C. Goble, and Neal F. Kassell. 1994. Passive Real-World Interface Props for Neurosurgical Visualization. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Boston, Massachusetts, USA) *(CHI '94)*. Association for Computing Machinery, New York, NY, USA, 452–458. https://doi.org/10.1145/191666.191821

[14] Brent Edward Insko. 2001. *Passive Haptics Significantly Enhances Virtual Environments*. Ph.D. Dissertation. University of North Carolina at Chapel Hill. http://www.cs.unc.edu/techreports/01-017.pdf

[15] Michael D. Jones, Zann Anderson, Jonna Häkkilä, Keith Cheverst, and Florian Daiber. 2018. HCI Outdoors: Understanding Human-Computer Interaction in Outdoor Recreation. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3170427.3170624

[16] Felix Kosmalla, André Zenner, Marco Speicher, Florian Daiber, Nico Herbig, and Antonio Krüger. 2017. Exploring Rock Climbing in Mixed Reality Environments. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI EA '17)*. Association for Computing Machinery, New York, NY, USA, 1787–1793. https://doi.org/10.1145/3027063.3053110

[17] Jaeyeon Lee, Mike Sinclair, Mar Gonzalez-Franco, Eyal Ofek, and Christian Holz. 2019. TORC: A Virtual Reality Controller for In-Hand High-Dexterity Finger Interaction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300301

[18] Pedro Lopes, Sijing You, Lung-Pan Cheng, Sebastian Marwecki, and Patrick Baudisch. 2017. Providing Haptics to Walls & Heavy Objects in Virtual Reality by Means of Electrical Muscle Stimulation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 1471–1482. https://doi.org/10.1145/3025453.3025600

[19] Nimesha Ranasinghe, Pravar Jain, Shienny Karwita, David Tolley, and Ellen Yi-Luen Do. 2017. Ambiotherm: Enhancing Sense of Presence in Virtual Reality by Simulating Real-World Environmental Conditions. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 1731–1742. https://doi.org/10.1145/3025453.3025723

[20] Peter Schulz, Dmitry Alexandrovsky, Felix Putze, Rainer Malaka, and Johannes Schöning. 2019. The Role of Physical Props in VR Climbing Environments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300413

[21] A. L. Simeone. 2015. Substitutional reality: Towards a research agenda. In *IEEE 1st Workshop on Everyday Virtual Reality (WEVR)*. 19–22.

[22] Adalberto L. Simeone, Mohamed Khamis, Augusto Esteves, Florian Daiber, Matjaž Kljun, Klen Čopič Pucihar, Poika Isokoski, and Jan Gugenheimer. 2020. International Workshop on Cross-Reality (XR) Interaction. In *Companion Proceedings of the 2020 Conference on Interactive Surfaces and Spaces* (Virtual Event, Portugal) *(ISS '20)*. Association for Computing Machinery, New York, NY, USA, 111–114. https://doi.org/10.1145/3380867.3424551

[23] Adalberto L. Simeone, Eduardo Velloso, and Hans Gellersen. 2015. Substitutional Reality: Using the Physical Environment to Design Virtual Reality Experiences. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3307–3316. https://doi.org/10.1145/2702123.2702389

[24] Mandayam A. Srinivasan and Cagatay Basdogan. 1997. Haptics in virtual environments: Taxonomy, research status, and challenges. *Computers & Graphics* 21, 4 (1997), 393 – 404. https://doi.org/10.1016/S0097-8493(97)00030-7 Haptic Displays in Virtual Environments and Computer Graphics in Korea.

[25] Frank Steinicke, Hrvoje Benko, Antonio Krüger, Daniel Keefe, Jean-Baptiste de la Riviére, Ken Anderson, Jonna Häkkilä, Leena Arhippainen, and Minna Pakanen. 2012. The 3rd Dimension of CHI (3DCHI): Touching and Designing 3D User Interfaces. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI EA '12)*. Association for Computing Machinery, New York, NY, USA, 2695–2698. https://doi.org/10.1145/2212776.2212698

[26] Eric Whitmire, Hrvoje Benko, Christian Holz, Eyal Ofek, and Mike Sinclair. 2018. Haptic Revolver: Touch, Shear, Texture, and Shape Rendering on a Reconfigurable Virtual Reality Controller. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3173660

[27] Andre Zenner and Antonio Kruger. 2017. Shifty: A Weight-Shifting Dynamic Passive Haptic Proxy to Enhance Object Perception in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics* 23, 4 (April 2017), 1285–1294. https://doi.org/10.1109/TVCG.2017.2656978

[28] André Zenner and Antonio Krüger. 2019. Drag:On: A Virtual Reality Controller Providing Haptic Feedback Based on Drag and Weight Shift. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300441

[29] Yuhang Zhao, Cynthia L. Bennett, Hrvoje Benko, Edward Cutrell, Christian Holz, Meredith Ringel Morris, and Mike Sinclair. 2018. Enabling People with Visual Impairments to Navigate Virtual Reality with a Haptic and Auditory Cane Simulation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3173574.3173690