Wizard of Props: Integrating Physical Props and VR for Interactive Design

ANONYMOUS AUTHOR(S)

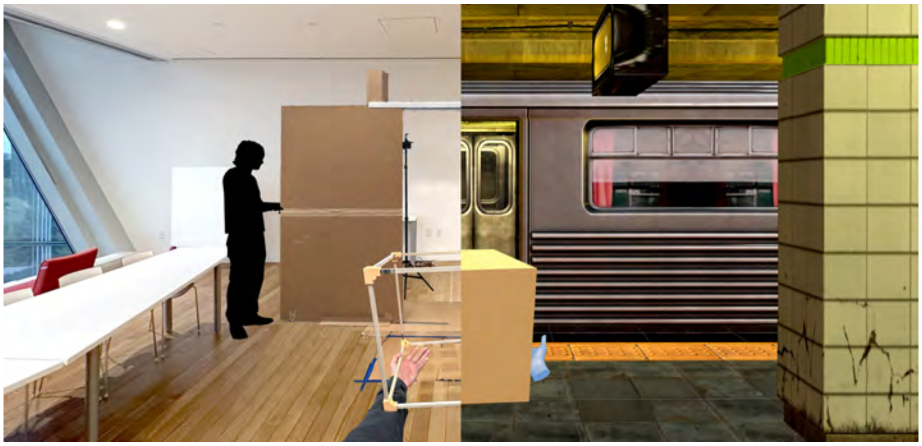

Fig. 1. The WoP combines physical props and virtual interaction to enable designers to understand the implications of embodiment in user interaction

Designers of physically interactive systems (e.g., architects, stage designers, and tangible device designers) employ a collection of design methods in their workflow. However, a dichotomy can be observed between the tangible and digital methods, as constructing an elaborated physical prototype is time-consuming and costly, while interacting with digital models lacks the embodiment of the product. This paper proposes a hybrid design system called Wizard of Props (WoP) that integrates full-scale physical props with Virtual Reality visualization to support interactive design. Our formative study (*N=8*), where participants designed an interactive door, compares WoP with the conventional workflow with hand-sketching and 3D design software. Our observations indicate that WoP fostered novel insights through enhancing spatial awareness, immersion, and tactile feedback, though its relationship with the conventional counterpart should be categorized as a complement rather than a replacement. Potential implications of WoP include tangible prototyping and interactive entertainment.

CCS Concepts: • **Human-centered computing** → **Systems and tools for interaction design**; *Mixed / augmented reality*; *User studies.*

Additional Key Words and Phrases: Human-Computer Interaction (HCI), Design / Design Methods, Embodied Interaction, Gestural / Whole-body Interaction, Tangible Interaction, Physicality

ACM Reference Format:

Anonymous Author(s). 2023. Wizard of Props: Integrating Physical Props and VR for Interactive Design. In *TEI '23: Tangible, Embedded, and Embodied Interaction, February 26 – March 1, 2023, Warsaw, Poland*. ACM, New York, NY, USA, 9 pages. https://doi.org/XXXXXXX.XXXXXXX

1 INTRODUCTION

Designers of physically interactive systems–architects, furniture designers, stage designers, and tangible device designers–employ a spectrum of methodologies in their workflow. For example, they might employ conceptual sketching with paper and pen, Computer-Aided Design with programs, interactive prototyping using Game Engines, and physical modeling with material exploration, digital fabrication, and electrical hardware development. Generally, we can categorize the approaches as either physically or digitally based. The physically-based methods use tangible archetypes to connect to reality [9], promote bodily understanding of the context [4], and support tactile and auditory senses beyond vision [2], but they are inflexible and can be costly. On the other hand, digital-based techniques can achieve high-fidelity visualization at a greatly reduced time and cost [2], but they lack the multimodal embodiment of actual products, and therefore, cannot provide designers with a comprehensive understanding of the tacit knowledge that tangible interaction provides [16].

Mixed prototyping, which mixes physical and digital modalities, can help overcome these limitations [22]. Our work expands mixed prototyping to the space of bodily interaction. In this paper, we introduce the Wizard of Props (WoP) design system, which combines physical props with virtual interaction to enable designers to explore the implications of embodiment. We demonstrate the WoP system in the format of an interactive sliding door. (This task was inspired by Ju's use of door opening as an entryway to understanding implicit interaction [13].) We describe the architecture of WoP, which consists of a full-scale physical cardboard prop for embodied studies, an interactive virtual environment for realistic visualization, and a tracking component that synchronizes the location and movement of the hybrid realities.

To evaluate Wizard of Props in an actual design workflow and to contrast it with the conventional process of hand sketching supported by 3D design software, we conducted a formative study (*N=8*) using both WoP and the conventional method for the task of designing the interactive door. Our results show that WoP enhances the designer's spatial awareness of contacts, and we analyze how it was used *in conjunction* with traditional methods that we sought to compare it to. This leads to the discussion of potential next steps and applications for such a system.

2 RELATED WORK

Previous works have explored the application of Virtual Reality (VR) in design and the integration of VR with physical props to bring haptic feedback to the virtual experience. Additionally, researchers have applied the concept of the Wizard of Oz to the hybrid system. They would actuate the physical props and adapt the tangible environment to the virtual scene. Our work extends the existing framework with a tracking system to synchronize the virtual model with the physical props, allowing designers to explore embodied interaction concurrently in the hybrid realms.

Virtual Reality for design. Virtual Reality has been widely adapted and integrated into the workflow by the design industry. Through immersive renderings and spatial interactions within the virtual environment, VR could enhance designers' cognitive actions and creativity [15], to help them empirically evaluate spatial relations and interactions [8, 12, 14, 23]. The other generative implication of VR in the design space is the embodiment of the designer's gestural actions [6, 11, 21]. Although there is a handful of commercialized VR applications for generative sketching and modeling (e.g., Gravity Sketch[1], Tilt Brush[2], and Arkio[3]), the motion controller-based input interface does not provide enough tangible constraints to the designers [6].

[1]https://www.gravitysketch.com
[2]https://www.tiltbrush.com/
[3]https://www.arkio.is/

Mixed prototyping. Researchers, such as Ferrise et al. [7] and Bordegoni et al. [3], have integrated the immersion of VR representation with haptic devices to provide a layer of tactile realism in the design workflow and help designers assess their products. In such a Substitutional Reality, every object in the physical world could be paired with a counterpart in the virtual realm [19]. The physical props could either passively provide a realistic touch to the user who is experiencing the virtual environment, such as the walkable pin-array in Elevate [10] and the climbing props for VR climbing [17], or actively vibrate or stretch to display specific tactile feedback as shown in project HexTouch [24] and QuadStretch [18]. With additional physical devices, including a tablet, a stylus, or a pair of haptic gloves, an additional layer of constraints could be provided to the generative sketching and modeling workflow in VR [6, 11, 21].

Actuation of physical props. The concept of Wizard of Oz has been adapted from conventional human-computer interaction prototyping to the mixed prototyping workflow, where designers could actuate the props in the physical world, simulating intelligent systems in the virtual world. A number of research projects use actuated physical props for room-scale prototyping. For instance, TurkDeck reconstructs the tactile environment of a room with movable panels operated by a group of participants [5]. RoomShift incorporates a group of shape-changing robots to dynamically transform the tangible environment [20]. In both studies, the transformation of the tangible space is done in real time as the experiencer is immersed in the VR environment. In the work of Sang-Gyun An et al., a group of designers collaboratively operates the physical proxies such as the steering wheel to construct a convincing prototype of an automotive interior for the designer wearing VR headset [1].

3 DESIGN AND IMPLEMENTATION

Our proposed Wizard of Props (WoP) system consists of three components: a full-scale cardboard prop capturing the geometry and mechanism of the target interactive object, a high-fidelity digital model of the object and the environment it rests in, and a tracking system that synchronizes the movement of the cardboard prop with the virtual object. We selected the interaction around a sliding door as our starting point, as it is reasonably scaled to involve full-body movements and is relatively simple because its sliding motion only has one degree of freedom (DoF). This helps narrow down the variance while providing enough design space to experiment with in the formative studies.

The physical prop. The physical prop (Figure 2.A) of the WoP system is made up of a cardboard frame and two cardboard door panels on casters, allowing the panels to slide with one DoF, forming a bilateral opening door. During the study, the participant who acted as an actuator could pull or push the door dashes with any anticipated speed in either direction. Markers with generated QR codes are attached to each door panel and are captured by the inbuilt camera of a mobile phone for synchronization with the virtual scene.

Additionally, a framed box is incorporated into the study, along with its virtual replica, to simulate the experience of carrying a box. The transparent framed design allows inside-out tracking from the Meta Quest 2[4] VR headset to track the hand positions, based on which the box's location and rotation are estimated. A virtual box is rendered accordingly.

The virtual environment. We developed a virtual environment with Unity 3D and displayed it to the participants through a head-mounted VR display (HMD) (Figure 2.C and 2.D). The virtual scene consists of a subway station with a boarding train[5]. Two movable door panels are programmed to follow the movement of the physical door panels with the synchronization system. The high-fidelity of the virtual model guarantees participants a convincing in-situ experience.

[4]https://www.meta.com/quest/products/quest-2/
[5]https://www.cgtrader.com/3d-models/interior/other/subway-metro-station

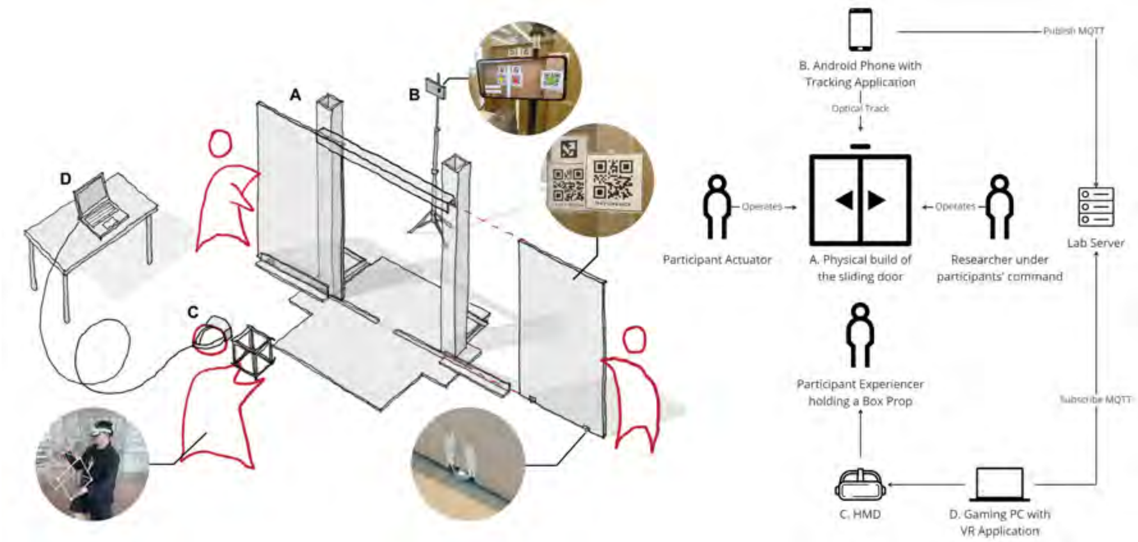

Fig. 2. Diagram of the Wizard of Props System

The hybrid synchronization. The spatial and movement synchronization between the physical prop and the virtual twin is crucial to the WoP system to support an immersive design experience and to ensure users' safety. In our implementation, we introduced an algorithm that spatially aligns the virtual scene with the physical prop through a series of gestural commands. In the VR application with hand-tracking enabled, the researcher would first use the right index finger to point at the central origin of the door and then trace the orientation of the door panels with the same finger. The virtual scene would relocate and reorient itself to match the transform of the physical prop.

We also set up an optical tracker on a tripod behind the door prop (Figure 2.B). This tracker consists of an Android phone running an Augmented Reality (AR) application based on the ARCore[6]. Markers with generated QR codes are printed and taped onto the door dashes. The AR application tracks the spatial positions of the markers, converts the movement data into a string message, and publishes the news to a central server using the MQTT network messaging protocol[7]. The central MQTT broker posts commands to the client VR application, which will responsively update the position of the door dashes in the virtual scene.

4 USER STUDY

We conducted a formative pilot study to explore the performance of the Wizard of Props in an actual design workflow and compare it with the more-conventional design workflow using hand sketching supported by the Unity program.

Participants. We recruited 8 participants from local universities (5 female, 3 male). They all have design-tech-related backgrounds ranging from Design, Human-Computer Interaction, and Software Engineering, and their ages range from 19 to 22 years old. They were split into four groups of two randomly and were requested to collectively solve an interactive design problem using the two design systems (the WoP and the conventional workflow) at random orders. We decided to conduct the study in groups because it replicates actual design practices that are always collaborative. It

[6]https://developers.google.com/ar
[7]https://mqtt.org

also promotes in-group discussions that could reflect the participants' active thoughts and feelings. Additionally, it allows the participants to simultaneously act as an actuator manipulating the physical prop and act as an experiencer viewing the virtual realm in the WoP, so that we could better analyze their collaborative workflow using our system.

Procedure. The study took approximately 40 minutes to complete and consists of four sections:

(1) *Study Introduction:* We explained the design task that they were expected to complete during the study. The task was to design a subway door-opening motion to serve an approaching passenger who is carrying a box with both hands. We encouraged participants to let their imaginations run wild by disregarding any practical restrictions. The overarching idea is to design an exciting yet novel interaction.

(2, 3) *Design Phase One and Two:* We asked each team to work on the same design task using the two workflows: the WoP and the conventional workflow, at a random sequence in the two consecutive design phases. In the conventional case (Figure 3.A), the participants are provided with paper and pen to sketch and outline their ideas, and they also have access to an interactive visualization of the subway door scene in Unity, with which they can drag the door panels with a mouse and "animate" the motion. On the other hand, Using the WoP system (Figure 3.B), the participants would operate the door prop physically and experience the immersive subway scene virtually. They would command the researcher to operate the other half of the sliding door.

In each design phase, the participants would spend eight minutes designing and four minutes sharing and discussing their outcomes with the researchers. In this study, two groups started with the WoP workflow as their first case, while the other two worked in the opposite order.

(4) *Focus Group Discussion:* We ended the study with a semi-structured discussion focused on participants' experiences and reflections on the design process, rather than their proposed design product. We also asked for their critique of the two design methods.

During the study, we documented, through photographs, the physical study environment, and through video, the participants' interaction during the two design phases and the final discussion. We also screen-recorded the Unity visualization program in the conventional case and the VR perspective in the Wizard of Props case.

5 RESULTS AND DISCUSSION

During the formative study, the four pairs of participants applied both the Wizard of Props and a more-conventional design workflow with hand sketching and Unity software to the task of designing the opening motion of a subway door. As a result, we received four differently behaving doors, including an active door that jiggles to "talk" to the passenger, an annoying door that always contradicts the passenger's expectation, an omniscient door that incorporates sensors to read the passenger's intention, and a shy door that only reacts when the passenger is not facing it directly.

After reviewing the video documentation of the design process and focus group discussion, and analyzing the similarities and differences between the participant's bodily and speech actions in the two conditions, we compiled a set of benefits and challenges that the teams experienced while using the Wizard of Props system for interactive design.

Spatial awareness insights. The participants demonstrated their understanding of the spatial relationship in both the WoP system and the baseline conventional condition. When using Unity in the conventional workflow, they frequently pointed at specific locations on the screen to indicate the position of motion or weight sensors, the height of the light indicator, or the direction of the door motion. Since they could freely see the physical door structure in the lab, in some instances, they would naturally turn around and refer to the cardboard door.

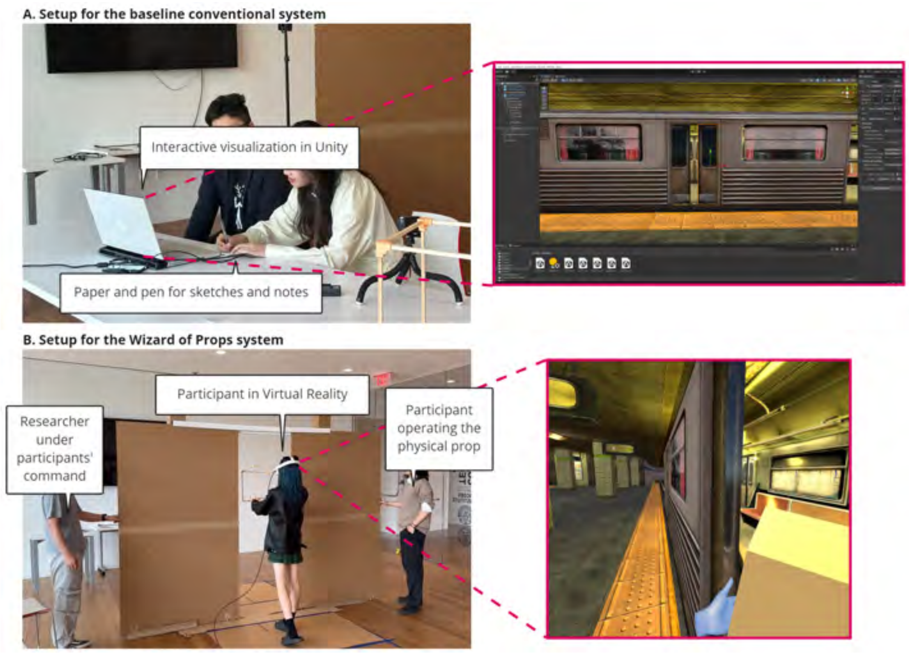

Fig. 3. Experiment Setup for the tabletop and WoP systems

In the WoP system, we observed that the enhanced spatial awareness led to an emphasis on the asymmetrical motion of the door. In both groups (2 out of 2) who started with the WoP, the participants designed doors that respond to the incoming position of the passenger. One matched the center line of the opening to the passenger position, while the other blocked the way of the passenger with one door and opened the other half to express annoyance. In contrast, all groups (2 out of 2) with the baseline condition as their first case ended up with symmetrical door designs.

Better understanding of the scale also helped with decision making, as one group commented, "*(In the baseline condition) we decided to open the door the same amount as the width of the passenger, but in VR we saw that the actual subway door is quite narrow and we almost always opened the whole door.*" They updated their design accordingly.

Experiencing the interaction is as important as designing it. Being a designer does not give a comprehensive and responsive understanding of the design outcome. A WoP provides participants with the double role of an experimenter and a designer. Experiencing the interaction immersively helped with decision-making.

We noted that one group decided to modify the opening duration of their door from 30 seconds, an arbitrary number they chose in the baseline condition, to 5 seconds after acting it out with the WoP. They explained, "*The door I see in VR is slightly different from the cardboard door, so setting the open time to 5 seconds is more reasonable*". The other group focused on the speed of the door. In baseline condition, they used "fast" to describe the motion, but in WoP, the participant experiencing the virtual environment would verbally tell the other participant operating the door to be "slightly faster" or "a bit slower". The sensation of speed is much more precise after experiencing the motions immersively.

Ideas that are made possible by the systems. Because of their different characteristics, the baseline and WoP both helped the groups raise novel ideas on the design. A handful of such ideas were inspired only by a specific design system.

For instance, the physical construction of the cardboard door let a group to remove a light indicator they came up with in their first design phase with conventional workflow. Through acting the design out with WoP, they realized that the mechanical sound and motion of the jiggling door action is auditorily and visually obvious enough to communicate the alert that the door is about to close. One participant commented that "*The shaky cardboard emulates the (disrepaired) condition of the actual subway system*".

The fact that the participants in the virtual experience held a physical box prop in their hands led to a series of interactions. Two groups (2 out of 4) decided to use the box prop to block the door. Another group raised the idea to "*knock the door with the box in a certain pattern and unlock the door with Morse Code*". One group also used the box to indicate frustration. Their annoying door always blocks the passenger from getting onto the train. In the end, the passenger would be really frustrated and tired, and they would throw the box onto the ground. "*That is when the door returns to normal*".

The conventional workflow also led to original design decisions. In Unity, one group navigated to the perspective from within the train and designed the interaction from the opposite side. This perspective was not possible in the current implementation of WoP because standing inside the train would block the tracking system behind the door. "*Unity provides the designer's perspective as it gives me more control over the scene. In VR I feel more like a user*".

Inherent limitations of the systems. Both the conventional and the WoP systems have their limitations. Participants reported limitations in the setup process and the tracking system of the WoP: one participant noted, "*Every time (we use the WoP), we have to set up and align the positions, but in tabletop, we do not have to worry about all this. It entangles more work to use the VR system.*" Meanwhile, the juvenile system will occasionally incur miscellaneous errors, such as tracking lost and misalignment, and thus the VR system requires recalibration on a frequent basis. Additionally, the lack of full-body tracking restrains the method participants could potentially interact with the door. Although they cannot see their feet in VR, two groups (2 out of 4) used one foot to block the closing door. The participants had to peek through the headset's gap to check their feet's exact position. Similarly, almost all participants demonstrated hesitation when they first walked through the door in VR. One participant noted, "*I'm not sure where I'm stepping. I'm worried that the physical door might still be in the way.*"

The current baseline condition uses Unity as an interactive visualizer, which might not be familiar to all participants. Three groups (3 out of 4) demonstrated confusion through gestures and expressions. They asked for help moving the door back to its original position, changing perspective, or turning on the positional pivot point.

What is the right sequence? In this pilot study, two groups (2 out of 4) did the conventional condition prior to the WoP, and the rest (2 out of 4) did the same experiment in reverse order. Participants were asked about their opinions on what should be the right sequence. One group that started with WoP argued that "*Our sequence is reasonable because VR is great for brainstorming. We can go through different ideas and visualize them. With that experience, we can then document the idea with Unity and paper. I personally prefer this workflow.*" However, the other group who started with the baseline stated, "*(In the baseline) I can write down the sequence of commands and actions and (in WoP) we can go through them and test them all out. It is more efficient to talk to each other and discuss (in the baseline) because we are face-to-face.*" One group who started with WoP raised new ideas in their tabletop iteration, "*We didn't test some feelings in VR because of the time frame, such as jiggling. I would love to actually try it out in VR and see if it works*"

Design is an iterative process. The Wizard of Props workflow should not outcompete and replace the existing design techniques. However, it should be integrated into the iterative process to bring novel perspectives to the designers, help them validate their proposals, and collectively reduce inherent biases in the individual design systems.

6 FUTURE WORK

Based on the insights gathered from this work in progress, we plan to address the following limitations in future work: We acknowledge that the study participants were recruited from an academic environment, which may have led to a biased outcome. For a future participatory study, we will recruit design practitioners from the industry, to learn how this method can be integrated into real-world design workflows. We will improve the tracking system to more reliably capture the physical props and the participants body. Based on the study feedback, we will simplify the setup process for the alignment between the physical and virtual environments.

We anticipate that WoP is suitable for general interactive design beyond the door interaction. We will develop a set of physical units that supports tracking and essential mechanisms, a VR template project, and a protocol for setting up the physical prop, the VR world, and their synchronization for any interactive system. We would like to see if this specific design system, a physical model with VR augmentation, could be transplanted and integrated into the rapid prototyping phase of a future standardized workflow of interactive design.

7 CONCLUSIONS

In this paper, we proposed the Wizard of Props (WoP), a hybrid design system that synchronizes a physical prop with a virtual environment to benefit from the embodiment of the user interaction and the immersion and flexibility of the digital representation. Our formative study (*N=8*) with the WoP proved that its multimodal nature could help designers better understand spatial relationships, explore multisensory interactions, and unveil implicit concepts. Contrasting it with the conventional design workflow that utilizes hand sketching supported by 3D modeling software, we concluded that WoP performs well as a complement to the design process, but it should not replace any existing design tool. Conversely, we discussed WoP's limitations, including its preliminary tracking system and inconvenient setup process. For our next phase, we will improve the reliability, usability, and adaptability of the Wizard of Props. The ultimate goal is to extend the WoP beyond the interactive door design. It could potentially be applied to prototyping other tangible interactions, and it could be used as a product for immersive and interactive entertainment purposes.

8 ACKNOWLEDGMENTS

This section is hidden because of anonymous consideration.

REFERENCES

[1] Sang-Gyun An, Yongkwan Kim, Joon Hyub Lee, and Seok-Hyung Bae. 2017. Collaborative Experience Prototyping of Automotive Interior in VR with 3D Sketching and Haptic Helpers. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Oldenburg, Germany) *(AutomotiveUI '17)*. Association for Computing Machinery, New York, NY, USA, 183–192. https://doi.org/10.1145/3122986.3123002

[2] Loris Barbieri, Agostino Angilica, Fabio Bruno, and Maurizio Muzzupappa. 2013. Mixed prototyping with configurable physical archetype for usability evaluation of product interfaces. *Computers in Industry* 64, 3 (2013), 310–323. https://doi.org/10.1016/j.compind.2012.11.010

[3] Monica Bordegoni, Umberto Cugini, Giandomenico Caruso, and Samuele Polistina. 2009. Mixed prototyping for product assessment: A reference framework. *International Journal on Interactive Design and Manufacturing (IJIDeM)* 3 (08 2009), 177–187. https://doi.org/10.1007/s12008-009-0073-9

[4] Eva Brandt and Camilla Grunnet. 2000. Evoking the future: drama and props in user centered design.

[5] Lung-Pan Cheng, Thijs Roumen, Hannes Rantzsch, Sven Köhler, Patrick Schmidt, Robert Kovacs, Johannes Jasper, Jonas Kemper, and Patrick Baudisch. 2015. TurkDeck: Physical Virtual Reality Based on People. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software amp; Technology* (Charlotte, NC, USA) *(UIST '15)*. Association for Computing Machinery, New York, NY, USA, 417–426. https://doi.org/10.1145/2807442.2807463

[6] Tobias Drey, Jan Gugenheimer, Julian Karlbauer, Maximilian Milo, and Enrico Rukzio. 2020. VRSketchIn: Exploring the Design Space of Pen and Tablet Interaction for 3D Sketching in Virtual Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376628

[7] Francesco Ferrise, Monica Bordegoni, and Joseba Lizaranzu. 2010. Product Design Review Application Based on a Vision-Sound-Haptic Interface. In *Haptic and Audio Interaction Design*, Rolf Nordahl, Stefania Serafin, Federico Fontana, and Stephen Brewster (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 169–178.

[8] David Goedicke, Carmel Zolkov, Natalie Friedman, Talia Wise, Avi Parush, and Wendy Ju. 2022. Strangers in a Strange Land: New Experimental System for Understanding Driving Culture Using VR. *IEEE Transactions on Vehicular Technology* 71, 4 (2022), 3399–3413. https://doi.org/10.1109/TVT.2022.3152611

[9] Steve Howard, Jennie Carroll, John Murphy, and Jane Peck. 2002. Using 'endowed Props' in Scenario-Based Design. In *Proceedings of the Second Nordic Conference on Human-Computer Interaction* (Aarhus, Denmark) *(NordiCHI '02)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/572020.572022

[10] Seungwoo Je, Hyunseung Lim, Kongpyung Moon, Shan-Yuan Teng, Jas Brooks, Pedro Lopes, and Andrea Bianchi. 2021. Elevate: A Walkable Pin-Array for Large Shape-Changing Terrains. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 127, 11 pages. https://doi.org/10.1145/3411764.3445454

[11] Ying Jiang, Congyi Zhang, Hongbo Fu, Alberto Cannavò, Fabrizio Lamberti, Henry Y K Lau, and Wenping Wang. 2021. HandPainter - 3D Sketching in VR with Hand-Based Physical Proxy. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 412, 13 pages. https://doi.org/10.1145/3411764.3445302

[12] Dongsik Jo, Ungyeon Yang, and Wookho Son. 2007. Design Evaluation Using Virtual Reality Based Prototypes: Towards Realistic Visualization and Operations. In *Proceedings of the 9th International Conference on Human Computer Interaction with Mobile Devices and Services* (Singapore) *(MobileHCI '07)*. Association for Computing Machinery, New York, NY, USA, 246–258. https://doi.org/10.1145/1377999.1378014

[13] Wendy Ju. 2015. *The Design of Implicit Interactions.* The MIT Press.

[14] Chi-Yang Lee, Hsuan-Ming Chang, Chun-Heng Lin, Ming-Han Tsai, Wen-Chieh Lin, Pei-Hsien Hsu, I-Chen Lin, Yu-Shuen Wang, and Jung-Hong Chuang. 2017. VR Lighting Design. In *SIGGRAPH Asia 2017 Posters* (Bangkok, Thailand) *(SA '17)*. Association for Computing Machinery, New York, NY, USA, Article 53, 2 pages. https://doi.org/10.1145/3145690.3145741

[15] Jee Hyun Lee, Eun Kyoung Yang, and Zhong Yuan Sun. 2019. Design Cognitive Actions Stimulating Creativity in the VR Design Environment. In *Proceedings of the 2019 on Creativity and Cognition* (San Diego, CA, USA) *(Camp;C '19)*. Association for Computing Machinery, New York, NY, USA, 604–611. https://doi.org/10.1145/3325480.3326575

[16] B. Moggridge and B. Atkinson. 2007. *Designing Interactions.* Footprint books. https://books.google.com/books?id=qxRRAAAAMAAJ

[17] 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

[18] Youngbo Aram Shim, Taejun Kim, and Geehyuk Lee. 2022. QuadStretch: A Forearm-Wearable Multi-Dimensional Skin Stretch Display for Immersive VR Haptic Feedback. In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI EA '22)*. Association for Computing Machinery, New York, NY, USA, Article 202, 4 pages. https://doi.org/10.1145/3491101.3519908

[19] 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

[20] Ryo Suzuki, Hooman Hedayati, Clement Zheng, James L. Bohn, Daniel Szafir, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2020. RoomShift: Room-Scale Dynamic Haptics for VR with Furniture-Moving Swarm Robots. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3313831.3376523

[21] Ryo Suzuki, Rubaiat Habib Kazi, Li-yi Wei, Stephen DiVerdi, Wilmot Li, and Daniel Leithinger. 2020. RealitySketch: Embedding Responsive Graphics and Visualizations in AR through Dynamic Sketching. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology* (Virtual Event, USA) *(UIST '20)*. Association for Computing Machinery, New York, NY, USA, 166–181. https://doi.org/10.1145/3379337.3415892

[22] Shan-Yuan Teng and Pedro Lopes. 2022. XR Needs "Mixed Feelings": Engineering Haptic Devices That Work in Both Virtual and Physical Realities. *XRDS* 29, 1 (oct 2022), 44–47. https://doi.org/10.1145/3558194

[23] Jianlin Wang, Wenyi Guo, Yuan Wei, Haoyu Zhang, Xiaohui Liu, and Chaokun Yan. 2021. A Virtual Reality System for Automation Assisted Interior Design. In *2021 International Conference on Human-Machine Interaction* (Guangzhou, China) *(ICHMI 2021)*. Association for Computing Machinery, New York, NY, USA, 29–34. https://doi.org/10.1145/3478472.3478474

[24] Ran Zhou, Yanzhe Wu, and Harpreet Sareen. 2020. HexTouch: A Wearable Haptic Robot for Complementary Interactions to Companion Agents in Virtual Reality. In *SIGGRAPH Asia 2020 Emerging Technologies* (Virtual Event, Republic of Korea) *(SA '20)*. Association for Computing Machinery, New York, NY, USA, Article 8, 2 pages. https://doi.org/10.1145/3415255.3422881