

# Fabricate It or Render It? Digital Fabrication vs. Virtual Reality for Creating Objects Instantly

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## ABSTRACT

In the technical human-computer interaction (HCI) community, two research fields that gained significant popularity in the last decade are digital fabrication and augmented/virtual reality (AR/VR). Although the two fields deal with different technical challenges, both aim for a single end goal: creating "objects" instantly – either by fabricating them physically or rendering them virtually. In this panel, we will discuss the pros and cons of both approaches, discuss which one may prevail in the future, and what opportunities exist for closer collaboration between researchers from the two research fields.

## KEYWORDS

digital fabrication, augmented reality, virtual reality, ubiquitous computing, tracking, markers, identification

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## 1 INTRODUCTION

Digital fabrication and AR/VR researchers represent a large fraction of the technical HCI community and have produced numerous papers at premier HCI venues, such as CHI, UIST, TEI, and DIS.

Digital fabrication and personal fabrication research aims to empower non-experts to design and produce their own physical artifacts, objects, and products using digital tools in their own homes [9]. While the technical approach of creating arbitrary objects on demand – using 3D printing – was protected by several patents, the technology rapidly transitioned from industry to the world after the first major patent expired in 2009. Since then, it has been commonly used by technology-enthusiastic *makers* and further developed by researchers, including those in the HCI and graphics communities [2]. Recent research enabled the fabrication of a greater variety of objects using different types of materials (e.g., conductive printing [8] or full color printing [1]), and proposed ways to lower the entry barrier to various digital fabrication methods beyond 3D printing (e.g., laser cutting [5], CNC milling [16], cutting plotter [22]) for non-experts.

Augmented, virtual, and mixed reality (AR/VR/MR) are intended to create an interactive experience that simulates or enhances the real world. While VR immerses users into a completely virtual environment, AR overlays the user's view of the real world with digitally generated content. The vision of creating a computer-generated, realistic world goes back to the 1960s, when Ivan Sutherland proposed his concept of the *Ultimate Display* [18], and the first AR head-mounted display prototype known as *The Sword of Damocles* [19]. While in the last decade the advancements in computer graphics, haptics, and other technical areas enabled the rapid development of more portable AR/VR tools, the unexpected demands of the COVID-19 pandemic also contributed to the rise in their popularity [12, 15, 17].

The two fields use fundamentally different hardware (e.g., 3D printers vs. headsets) and software tools (e.g., slicers vs. game engines) to build artifacts. However, their goals are similar: to create *objects* instantly – either by fabricating them physically or rendering them virtually. The objects should be able to be generated on demand and with the functionality and look desired by the user. These aspirations are true of many applications of both research fields. For example, in architectural design, a digital 3D model could be rendered in an AR/VR environment or a low-fidelity model could be 3D printed to experience a building before it is built. In medicine, surgeons can practice an operation using VR headsets or by 3D printing phantoms before performing it on the actual patient. The same can be said of many different applications in product design or market research, where experiencing and testing a virtual or low-fidelity product that does not yet exist is crucial [8].

In this panel, we will talk about how both fields have evolved in the last decade and how they were able to generate significant interest in the HCI community. We will discuss and compare the pros and cons of each research field, identify similarities and differences, as well as challenges and opportunities [3]. We will also draw conclusions about which one is more important for different applications. For example, while a 3D model can be virtually rendered faster using a VR headset rather than a 3D printer fabricating a physical sample, current VR headsets do not provide the same realistic haptic feedback as a 3D printed sample would be able to afford.

We will also discuss which field may prevail in the future, and whether there is room for closer collaboration between researchers from the two research fields. Several HCI papers have already demonstrated how the two fields could work together to achieve more sophisticated goals and to better assist users. For example, in *RoMA* [13], users can design CAD models in augmented reality while a 3D printing robotic arm physically constructs the model's features. By using AR as a tool, RoMA allows the designer to integrate real-world constraints into the object's design intuitively and rapidly. *MixFab* [20] is a mixed-reality environment that allows users without 3D modeling skills to create content for personal fabrication. The users can build new models using gestures or by 3D scanning existing physical objects. In *Situated Modeling* [10], users can draw 3D models by moving tangible 3D primitive shapes with fiducial markers attached on them. In this AR framework, new virtual objects can be designed in air and displayed alongside existing physical ones.

While these projects demonstrated how AR can be used as a tool to advance digital fabrication, AR research may also benefit from leveraging fabrication tools for various use cases, such as object identification and tracking [6]. For instance, *InfraredTags* [7] allows users to invisibly embed fiducial markers (e.g., *ArUco* [14]) into 3D printed objects so that objects can be unobtrusively identified and tracked in augmented reality applications. *LayerCode* [11] uses stereolithography to embed barcodes' bits into the individual layers of 3D printed objects, which can be used to estimate the 3D position of objects or to insert overlays in AR applications. Furthermore, many hardware tools for AR/VR are prototyped using 3D printers, as demonstrated by *Haptic Links* [21] or *CLAW* [4].

## 2 PANEL FORMAT

The panel includes **five panelists** and **one moderator**. It will be **hybrid** (i.e., held in-person with ability for panelists and attendees to participate virtually).

The panel will begin with the moderator introducing the panelists and the topic of discussion. The panelists will each be given two minutes to briefly summarize their current research and their view on the future of the two fields, optionally supported by 1-2 slides.

Next, the moderator will kick off the discussion by briefly explaining what led to recent interest in the fabrication and AR/VR research (e.g., the democratization of 3D printers or virtual reality headsets). Then, we will talk about the current state of the two fields, as well as their promise and potential. Following this, the panel will speculate about the future of both fields. This discussion is expected to cover the major portion of the allotted time. Throughout the panel session, careful moderation will ensure that all views are equally represented and that all panelists are given equal opportunity to speak. We expect that the following key questions will be addressed in the discussion:

- Is it safe to say that fabrication and AR/VR researchers strive for the same goal? What are some of the similarities and differences between the two fields?
- For what kinds of HCI applications is AR/VR more suitable than digital fabrication, and vice versa?
- How do you foresee the future of both research fields? Are we going through a hype?
- Is there room for closer collaboration between researchers from the two research fields?
- As technology becomes more affordable and compact, will there be an advanced desktop manufacturing machine or virtual reality headset in each home in the future?

Each question will be answered by one fabrication researcher and one AR/VR researcher. Each panelist will be asked to speak for no more than 3 minutes each.

After the introductions (15 minutes) and the initial discussion (30 minutes), the floor will be opened for a full-blown discussion with the audience. We would like to encourage a lively and interactive debate, given how timely and controversial the question is. The audience will be able to ask questions or provide comments on panelists' viewpoints. The discussion will be streamed on Zoom to allow for remote participation. Remote attendees will be able to ask questions through the chat function, which will be directed to the moderator and panelists with the help of a student volunteer.

**Logistical needs and hybrid requirements:** For the panel, we do not have any special logistical needs other than typical A/V support for a hybrid event. In case the panelist would like to display images, it is preferred to have a projector. Since the hybrid panel will allow remote participation, a camera setup for streaming on Zoom is desired. Alternatively, a student volunteer may stream the event via their mobile device or laptop. This person should be responsible for bringing up these questions to the panel. In addition, we would like to have 1-2 student volunteers to pass the microphone for questions and comments from the co-located audience.

### 3 PANELISTS

The panel will be facilitated by **Mustafa Doga Dogan**, a PhD candidate at the Massachusetts Institute of Technology (MIT). Dogan's doctoral work focuses on embedding tags and markers into everyday objects to identify or track them and to store information in them. He leverages digital fabrication methods such as 3D printing to achieve this. The panel is organized by Dogan and his PhD advisor **Stefanie Mueller**.

The panelists listed below were selected to balance the expertise in fabrication and AR/VR research.

**Patrick Baudisch**<sup>1</sup> is a Professor in Computer Science at Hasso Plattner Institute at Potsdam University and chair of the Human Computer Interaction Lab. After working on mobile devices, touch input, and natural user interfaces for several years, his current research focuses on personal fabrication, haptics, and virtual reality. Previously, he worked as a research scientist at Microsoft Research and Xerox PARC. He holds a PhD in Computer Science from Darmstadt University of Technology, Germany. He was inducted into the CHI Academy in 2013 and has been an ACM distinguished scientist since 2014.

**Hrvoje Benko**<sup>2</sup> is a Director of Research Science at Facebook Reality Labs Research, working on novel interactions, devices and interfaces for Augmented and Virtual Reality applications. He currently leads a multi-disciplinary organization that includes scientists and engineers with expertise in HCI, computer vision, machine learning, AI, neuroscience, robotics and cognitive psychology. His previous work at Microsoft Research was released as products, including Microsoft Touch Mouse and Microsoft Surface. He received his PhD in computer science from Columbia University in 2007.

**Michael Nebeling** is an Assistant Professor in the School of Information, where he leads the Information Interaction Lab. His lab investigates new methods, tools and technologies that enable users to interact with information in more natural and powerful ways, and also make it easier for designers to create more usable and effective user interfaces. Previously, he was a postdoctoral researcher and lecturer at the HCI Institute at Carnegie Mellon University and the Department of Computer Science at ETH Zurich, where he also obtained his PhD.

**Huaishu Peng** is an Assistant Professor in the Department of Computer Science of University of Maryland, College Park, where he works at the intersection of HCI and personal fabrication. He designs hardware and software systems to enable 3D modeling with interactive experiences and to manufacture functional objects with custom fabrication machines. He received his PhD in information science from Cornell University in 2018.

**Valkyrie Savage** is an Assistant Professor in the Department of Computer Science at the University of Copenhagen. Her work in HCI focuses on input devices and techniques mediated through sensing and digital fabrication. Specifically, she is interested in creating deeply custom interfaces that are adapted to users' bodies, contexts, and needs. She received her PhD in computer science from UC Berkeley in 2016 and also worked as a researcher at Tactual Labs.

<sup>1</sup>This Roumen, PhD candidate at Hasso Plattner Institute, will participate in the panel instead if Dr. Baudisch is unable to attend the conference in person.

<sup>2</sup>Dr. Benko will most likely arrive in New Orleans after May 1. **Thus, if possible, we request a date after May 1 for this panel.**

### REFERENCES

- [1] Vahid Babaei, Kiril Vidimče, Michael Foshey, Alexandre Kaspar, Piotr Didyk, and Wojciech Matusik. 2017. Color contouring for 3D printing. *ACM Transactions on Graphics* 36, 4 (July 2017), 1–15. <https://doi.org/10.1145/3072959.3073605>
- [2] Patrick Baudisch and Stefanie Mueller. 2017. Personal Fabrication. *Foundations and Trends® in Human-Computer Interaction* 10, 3–4 (2017), 165–293. <https://doi.org/10.1561/11000000055>
- [3] Hrvoje Benko. 2020. The Future of Mixed Reality Interactions. In *Companion Proceedings of the 2020 Conference on Interactive Surfaces and Spaces (ISS '20)*. Association for Computing Machinery, New York, NY, USA, 1. <https://doi.org/10.1145/3380867.3430136>
- [4] Inrak Choi, Eyal Ofek, Hrvoje Benko, Mike Sinclair, and Christian Holz. 2018. CLAW: A Multifunctional Handheld Haptic Controller for Grasping, Touching, and Triggering in Virtual Reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, Montreal QC Canada, 1–13. <https://doi.org/10.1145/3173574.3174228>
- [5] Mustafa Doga Dogan, Steven Vidal Acevedo Colon, Varnika Sinha, Kaan Akşit, and Stefanie Mueller. 2021. SensiCut: Material-Aware Laser Cutting Using Speckle Sensing and Deep Learning. In *Proceedings of the 34th Annual ACM Symposium on User Interface Software and Technology*. ACM, Virtual Event USA, 15. <https://doi.org/10.1145/3472749.3474733>
- [6] Mustafa Doga Dogan, Faraz Faruqi, Andrew Day Churchill, Kenneth Friedman, Leon Cheng, Sriram Subramanian, and Stefanie Mueller. 2020. G-ID: Identifying 3D Prints Using Slicing Parameters. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. <https://doi.org/10.1145/3313831.3376202>
- [7] Mustafa Doga Dogan, Ahmad Taka, Michael Lu, Yunyi Zhu, Akshat Kumar, Aakar Gupta, and Stefanie Mueller. 2022. InfraredTags: Embedding Invisible AR Markers and Barcodes Using Low-Cost, Infrared-Based 3D Printing and Imaging Tools. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New Orleans LA USA, 9. <https://doi.org/10.1145/3491102.3501951>
- [8] Jack Forman, Mustafa Doga Dogan, Hamilton Forsythe, and Hiroshi Ishii. 2020. DefeXtiles: 3D Printing Quasi-Woven Fabric via Under-Extrusion. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology (UIST '20)*. Association for Computing Machinery, New York, NY, USA, 1222–1233. <https://doi.org/10.1145/3379337.3415876>
- [9] N.A. Gershenfeld. 2005. *Fab: The Coming Revolution on Your Desktop—from Personal Computers to Personal Fabrication*. Basic Books. <https://books.google.com/books?id=Oil3bH6fKBkC>
- [10] Manfred Lau, Masaki Hirose, Akira Ohgawara, Jun Mitani, and Takeo Igarashi. 2012. Situated modeling: a shape-stamping interface with tangible primitives. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction (TEI '12)*. Association for Computing Machinery, New York, NY, USA, 275–282. <https://doi.org/10.1145/2148131.2148190>
- [11] Henrique Teles Maia, Dingzeyu Li, Yuan Yang, and Changxi Zheng. 2019. Layer-Code: optical barcodes for 3D printed shapes. *ACM Transactions on Graphics* 38, 4 (July 2019), 112:1–112:14. <https://doi.org/10.1145/3306346.3322960>
- [12] Benjamin Matthews, Zi Siang See, and Jamin Day. 2021. Crisis and extended realities: remote presence in the time of COVID-19. *Media International Australia* 178, 1 (Feb. 2021), 198–209. <https://doi.org/10.1177/1329878X20967165> Publisher: SAGE Publications Ltd.
- [13] Huaishu Peng, Jimmy Briggs, Cheng-Yao Wang, Kevin Guo, Joseph Kider, Stefanie Mueller, Patrick Baudisch, and François Guimbretière. 2018. RoMA: Interactive Fabrication with Augmented Reality and a Robotic 3D Printer. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. <https://doi.org/10.1145/3173574.3174153>
- [14] Francisco Romero-Ramirez, Rafael Muñoz-Salinas, and Rafael Medina-Carnicer. 2018. Speeded Up Detection of Squared Fiducial Markers. *Image and Vision Computing* 76 (June 2018). <https://doi.org/10.1016/j.imavis.2018.05.004>
- [15] Daniel Sarkady, Larissa Neuburger, and Roman Egger. 2021. Virtual Reality as a Travel Substitution Tool During COVID-19. In *Information and Communication Technologies in Tourism 2021*, Wolfgang Wörndl, Chulmo Koo, and Jason L. Stienmetz (Eds.). Springer International Publishing, Cham, 452–463. [https://doi.org/10.1007/978-3-030-65785-7\\_44](https://doi.org/10.1007/978-3-030-65785-7_44)
- [16] Eldon Schoop, Michelle Nguyen, Daniel Lim, Valkyrie Savage, Sean Follmer, and Björn Hartmann. 2016. Drill Sergeant: Supporting Physical Construction Projects through an Ecosystem of Augmented Tools. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, San Jose California USA, 1607–1614. <https://doi.org/10.1145/2851581.2892429>
- [17] Ravi Pratap Singh, Mohd Javaid, Ravinder Kataria, Mohit Tyagi, Abid Haleem, and Rajiv Suman. 2020. Significant applications of virtual reality for COVID-19 pandemic. *Diabetes & Metabolic Syndrome* 14, 4 (2020), 661–664. <https://doi.org/10.1016/j.dsx.2020.05.011>
- [18] Ivan E. Sutherland. 1965. The Ultimate Display. In *Proceedings of the IFIP Congress*. 506–508.

- [19] Ivan E. Sutherland. 1968. A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, fall joint computer conference, part I (AFIPS '68 (Fall, part I))*. Association for Computing Machinery, New York, NY, USA, 757–764. <https://doi.org/10.1145/1476589.1476686>
- [20] Christian Weichel, Manfred Lau, David Kim, Nicolas Villar, and Hans W. Gellersen. 2014. MixFab: a mixed-reality environment for personal fabrication. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, Toronto Ontario Canada, 3855–3864. <https://doi.org/10.1145/2556288.2557090>
- [21] 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*. ACM, Montreal QC Canada, 1–12. <https://doi.org/10.1145/3173574.3173660>
- [22] Junichi Yamaoka, Mustafa Doga Dogan, Katarina Bulovic, Kazuya Saito, Yoshihiro Kawahara, Yasuaki Kakehi, and Stefanie Mueller. 2019. FoldTronics: Creating 3D Objects with Integrated Electronics Using Foldable Honeycomb Structures. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, Glasgow, Scotland Uk, 1–14. <https://doi.org/10.1145/3290605.3300858>