Challenges and Opportunities of Printed Electronics for Smart Tangible Learning Applications for Extended Reality

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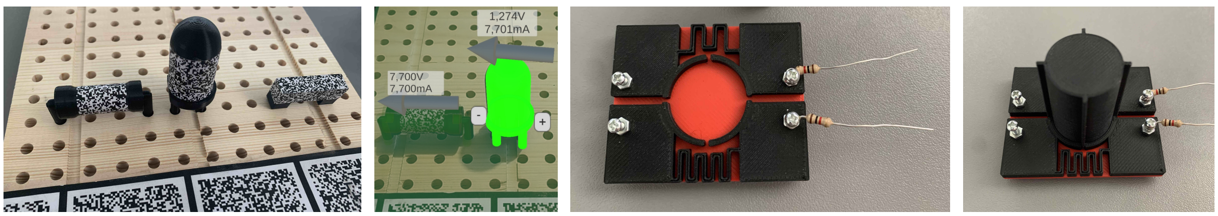

(a) (b) (c) (d)

Fig. 1. An overview of the scaled augmented electronics breadboard. **(a)** The wooden breadboard with the scaled non-functional components and their visual markers. **(b)** The mobile AR application shows that the circuit is functional and that the LED turns on. Here, the user could parameterize the value of the resistor and see the effect immediately. **(c)** Scaled test version of the pin detection concept. The top and bottom parts differ in their resistance. **(d)** Once a conductive pin is inserted, both resistance paths are shorted equally.

Extended reality (XR) applications become increasingly established tools to support users across a broad spectrum of tasks, including teaching environments for electronics and circuit design. While these offer fascinating possibilities of visualizing learning content, they lack the possibility of physical interaction. Here, tangible input devices provide an opportunity for engaging interactions with the learning content without the possible hazards of actual electronic components. This can provide effective and efficient interactions, important for meaningful learning experiences. In this paper we present and discuss our ongoing research on a tangible XR-supported smart breadboard, utilizing the possibilities of printed electronics.

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1 LEARNING ELECTRONIC CIRCUIT BUILDING

Learning to build functional electronic circuits can be challenging as internal processes remain mostly invisible. Furthermore, learners might fear physical harm or component damage of electronics which often includes beginners and children in particular. To address these issues, we explore XR to visualize internal processes of non-functional circuits [2]. We created a scaled and robust tangible kit shown in 1a), allowing to safely configure

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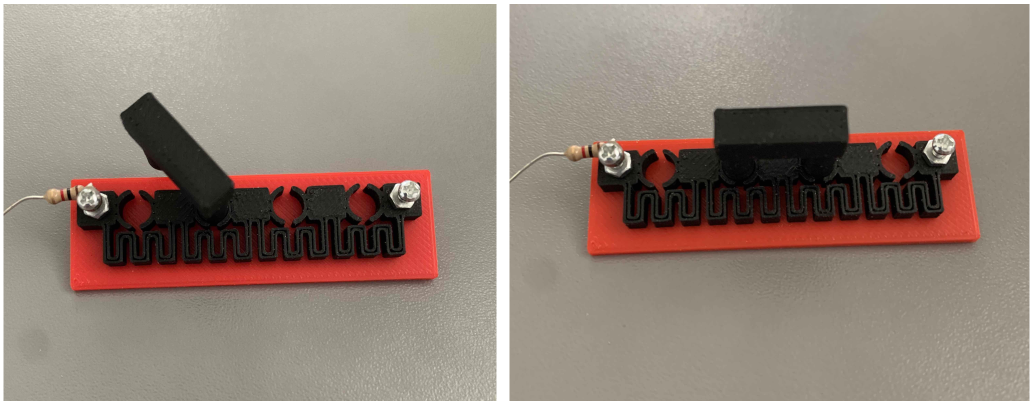

(a) (b)

Fig. 2. Proof-of-concept of the conductive pin hole concept with the target dimensions for the smart breadboard. Equal resistance paths travel around the pin holes and are shortened when **(a)** one pin or **(b)** two pins are inserted.

a circuit on a scaled non-functional breadboard. The user receives detailed information about internal processes through a mobile AR app, visualized in 1b). This circuit kit differs from related work on augmented electronics [1, 3, 4] in the fidelity of the components. Although the components are non-functional, they represent the form and shape of their real counterparts. The scaled breadboard is virtually interconnected in the same way as a real breadboard. That way, we aim to support the transfer of knowledge from the scaled kit to real ones.

The visual markers of the 3D printed components that can either be glued or printed with a multi-material printer allow to visually capture the circuit configuration. Another marker fixed to the wooden breadboard is used to determine the position of the components. This simple concept worked well in our first set of user evaluations. Yet, we note that the visual detection conflicts with the need to create and analyze complex circuits. As the number of placed components grows and the distance between the components is reduced, the time to detect all components significantly increases as well. In some cases, components might not be detected at all if they are partially blocked by other components. This leads to a key challenge: the reliable detection of complex tangible configurations that act as input and/or output for XR applications.

Recognizing the limitations of visual detection mechanisms, we decided to explore techniques to auto-detect configurations. Figures 1c and 1d show a first concept of a 3D printed pin hole that is made out of conductive material. To explore the concept, we printed two different resistance paths around the pin hole (i.e., the resistance of the bottom part is greater than the resistance of the upper part). Once a conductive pin is inserted (see Figure 1d), the total resistance is lowered, as the current moves directly through the center. This effect can be measured with a microcontroller. Figure 2 depicts an updated version with several pin holes and the target distance and size for the next iteration of the XR breadboard. Figure 3 shows one layer of a breadboard row with 14 pins.

All depicted prints were made with a multi-material printer and a mix of conductive and non-conductive filaments. To complete the breadboard and to detect multiple types of hardware component proxies, we aim to print three layers of separated conductive pin holes for each breadboard row. Component pins that are printed with a multi-material printer will differ in their conductivity across those three layers, allowing to detect the type and orientation of scaled hardware components placed on the final breadboard. We are planning to bring the latest breadboard, depicted as a rendered image with three pin detection layers in Figure 4 to the workshop and to show how the XR application provides detailed feedback on complex circuit configurations.

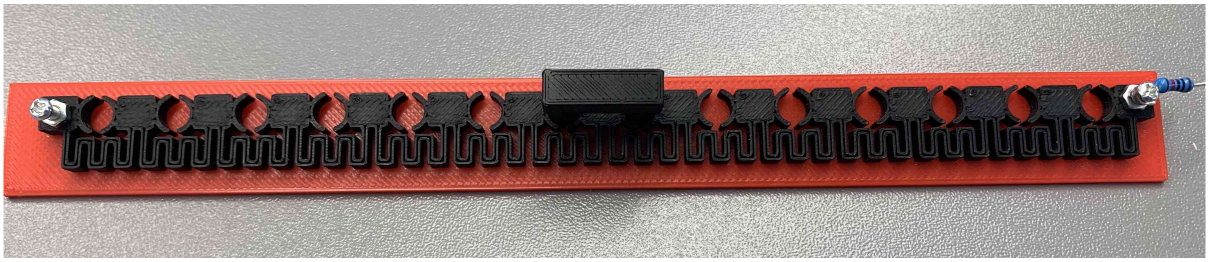

Fig. 3. A complete row of a single pin hole layer. The black jumper wire is detected as two resistance paths were shorted when the jumper wire was inserted.

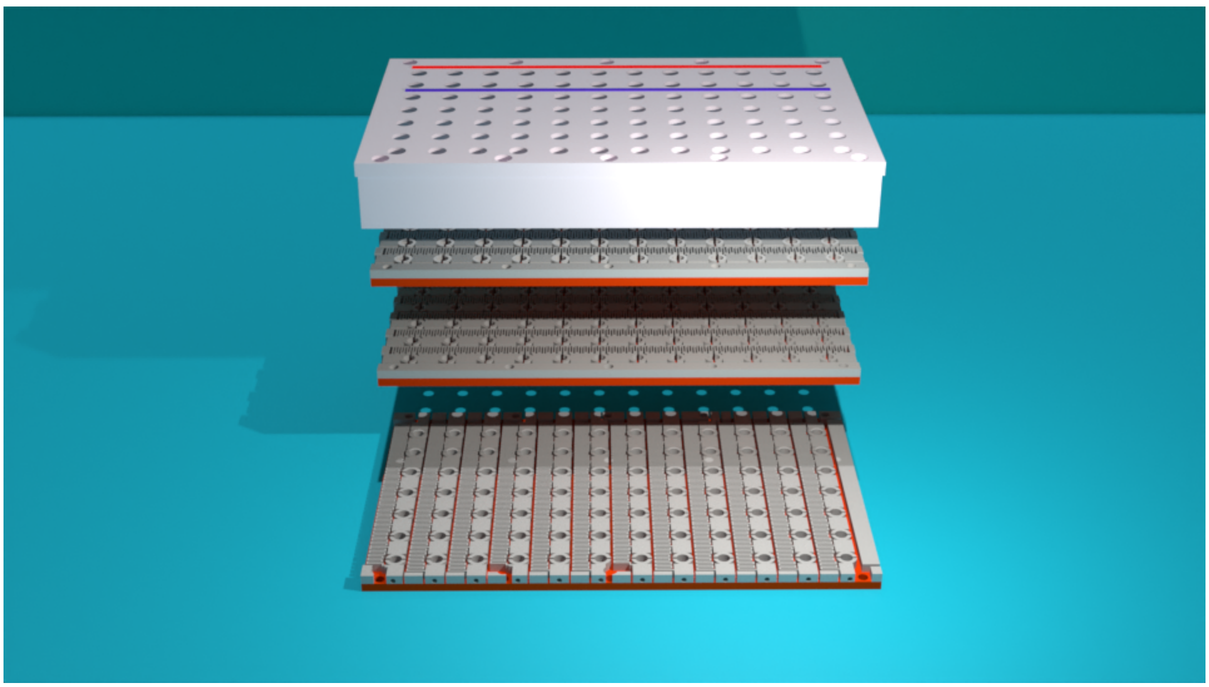

Fig. 4. A rendering of the latest breadboard version with three pin detection layers.

2 CONCLUSION

We presented challenges and opportunities for the design of smart objects for XR applications to facilitate the learning of electronic circuit building. The electronic circuit use case relates directly to the workshop theme of future paradigms for electronics toolkits. It attempts to increase access to making and physical computing, in particular across a young population. Yet, common visual circuit configuration detection faces limits. To address these challenges, we presented our ongoing work in the direction of smart breadboards that detect the configuration of 3D-printed hardware component proxies. We plan to bring the latest prototype with us to the workshop.

3 BIOGRAPHIES

Julian Rasch is an HCI Researcher and PhD Student at the Media Informatics Group at LMU Munich. His research focuses on the interaction between humans and digital systems to facilitate and augment this strong collaboration. His research interests include Perception & Interaction in XR, Interaction with AI Systems, Human Augmentation, Virtual Design & Engineering, and Future Applications of XR. Thanks to his background in Electrical Engineering & IT, he has knowledge and experience in hardware prototyping as well as methodological problem-solving.

Sebastian Feger is a Postdoc at LMU Munich, conducting research across a broad spectrum of HCI. He greatly enjoys designing smart objects and teaches electronics and physical computing with great enthusiasm. Sebastian perceives XR as a great opportunity to transform the way the wider society engages in making and digital fabrication. Recognizing the importance of configuring and navigating increasingly complex and data-rich mixed reality environments, Sebastian decided to focus on the design of smart objects for XR in his habilitation.

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