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A hybrid learning environment for collaborative learning in architectural robotics

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Keywords: Hybrid Learning Environments, Virtual Reality, Architectural Robotics, Human-Robot Interaction

Extended Abstract

We present a Hybrid Learning Environment (HLE) that supports collaborative learning in architectural robotics. The demand for robotics education has been growing owing to changes in related industries. This education requires specific physical equipment and skilled instructors, making it both time- and resource-intensive. To address this issue, new teaching methods and technologies are needed to make them more accessible using scarce resources. We introduced an ongoing project that responds to this need by integrating Virtual Reality (VR) and Human-Robot Interaction (HRI) technologies in an educational context. This project addresses educational activities in study programmes in which hands-on design thinking is fundamental, such as architecture, building technology, and product design studies. These programmes involve courses in which students use tangible tools and materials to develop, analyse, and present their ideas. They built physical models and prototypes to explore the spatial and material qualities of a design concept and to understand how a design would work in the physical world. These models are tools for students to think and interfaces for communication between fellow students and educators.

Similarly, this project focuses on a course that introduces students to architectural robotics in the Building Technology MSc. programme. It is a hands-on course based on experiential learning and learning-by-doing using a physical fabrication laboratory equipped with a UR5 robotic arm. In this course, students learn how to program and operate the robotic arm and use it to assemble a complex architectural design (Figure 1). There is a growing interest in the student community following this course. However, it is only offered to a limited number of students because of limited resources. The project aims to make education on this subject more accessible by enhancing the utilisation of existing infrastructure and staff hours, enabling students to personalise their learning experiences based on their skills and expectations, and ensuring continual access to the laboratory by utilising developments in online and blended learning. Moreover, it aims to enrich education through constructivist learning approaches that facilitate student-centred learning, aligning with theories within educational sciences (for example Bashabsheh *et al.*, 2019; Maroukakis *et al.*, 2023).

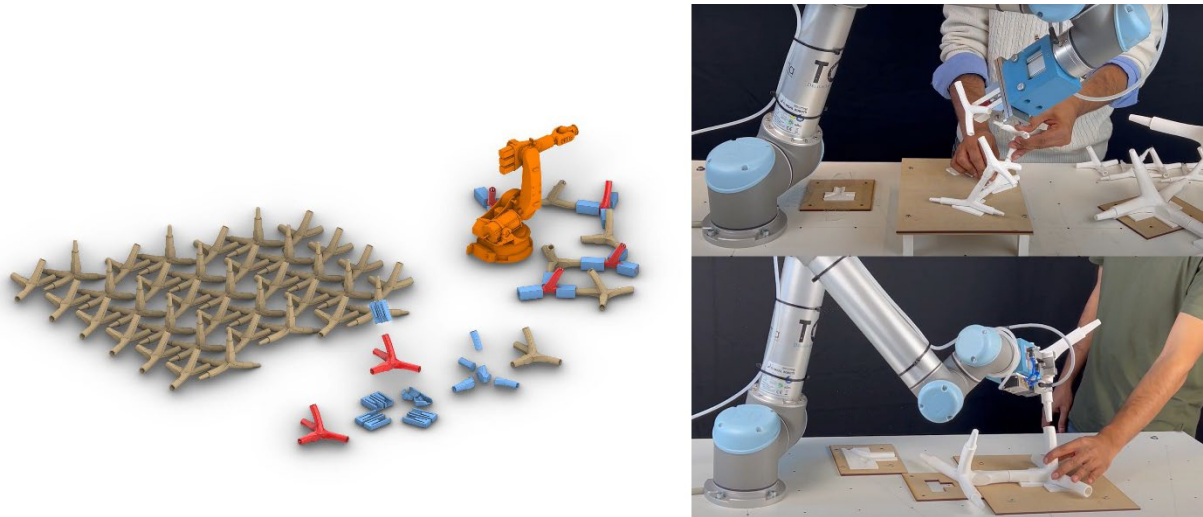


Figure 1. Example of a student project in which the robotic arm is used for discrete assembly of an architectural design.

According to (Norberg *et al.*, 2011), online and blended learning is a new normal, and they increase access to education for students, responding to their lifestyles through flexible learning opportunities. Current multimedia-based materials and platforms are fairly efficient and are widely used for audiovisual and verbal communication in online and blended learning. However, they cannot replace a workspace with physical materials and tangible tools such as model-making workshops or laboratories.

The technology of HLE was developed following related studies that aimed to integrate virtual environments with robotic fabrication (e.g., Cimino *et al.*, 2019; Coronado *et al.*, 2023; Dianatfar *et al.*, 2021; Wang *et al.*, 2018). It was developed by creating a digital twin of the existing laboratory and combining the two environments for real-time interaction. A digital twin was created using the Blender and Unity software. Communication between the virtual and physical workspaces is achieved through Transmission Control Protocol (TCP) (Figure 2) and a dedicated Web Server developed using JavaScript.

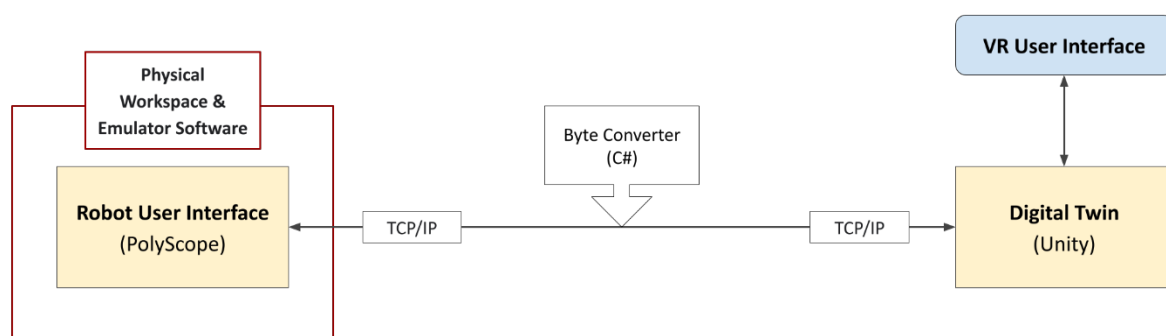


Figure 2. The diagram illustrating the communication between the physical robot and its digital twin through TCP.

The HLE enables students to practice the learning exercises in the virtual environment, allowing the scaling of the education to more extensive groups while making it possible for the students to experience customised learning based on their changing needs and skills. In

addition, it enables hybrid real-time collaboration between students and teachers, in which some users participate on-site, while others participate remotely.

Currently, tailor-made learning exercises are being developed to effectively utilise HLE and integrate it into courses. A series of test workshops was implemented to assess and improve its functionalities (Figure 3). These workshops demonstrated that the learning experience through VR is more intuitive, engaging, and realistic than the standard computer setup. This facilitates enhanced robot observation from multiple angles, helping in a comprehensive 3D understanding of its operations. Therefore, the empirical analysis of the initial project outcomes confirms that the acquisition of robot programming and operational skills can be sustained in a blended format by adopting an HLE that integrates the physical workspace with its digital twin in a VR environment. Moreover, it can facilitate effective remote and on-site collaboration, provided that communication methods are defined and well structured within the learning exercises.

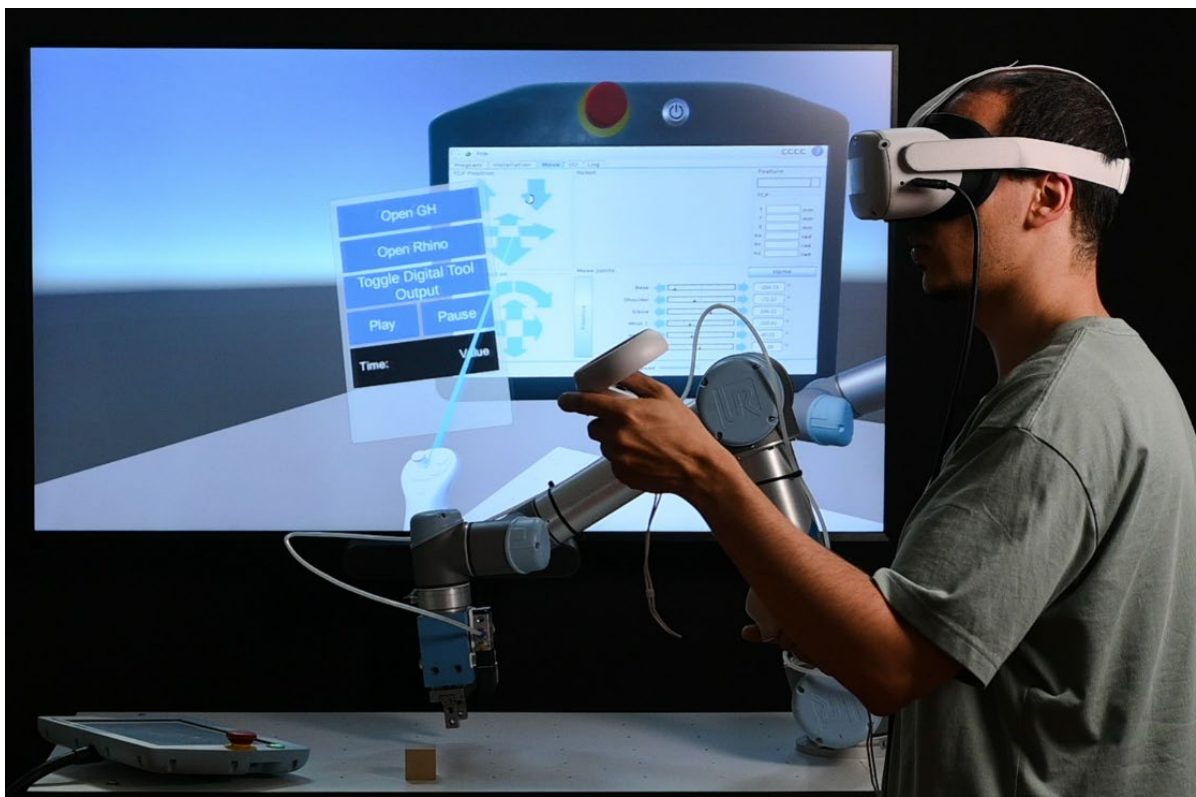


Figure 3. An image that shows the HLE in use.

According to the findings of this research, the most effective approach for establishing communication between a physical robot and its digital twin is to use the TCP protocol and manage the traffic between several software and hardware through a custom web server. This choice for TCP is justified by its capacity to mitigate latency issues, cost-free nature, and integration within existing robot software. The web server is used for accessible communication between several platforms, including multiple users. Using this method, multiple users can collaboratively participate in learning activities, enabling a blend of on-site and remote engagement.

Several aspects, including hardware accessibility, network safety, and network speed, must be discussed for future improvements in HLE. They can also incorporate tactile sensations into the VR experience and adopt a multisensory and multimodal approach for more effective learning. Learning exercise design plays a crucial role in the effective use of HLE. Collaboration between on-site participants and those engaging remotely requires precise structuring of learning exercises. They should include strategies to communicate information effectively. Eventually, the development of HLE will provide useful insights into the development of similar hybrid environments that can be used in actual fabrication tasks at construction sites.

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