IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 25 February 2025, accepted 26 March 2025, date of publication 28 March 2025, date of current version 7 April 2025.

Digital Object Identifier 10.1109/ACCESS.2025.3555930

RESEARCH ARTICLE

Enhancing the Educational Model Using Mixed Reality Technologies With Meta Quest 3: A Usability Analysis Using IBM-CSUQ

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ABSTRACT In today's education landscape, there is a lack of effective digital tools for hands-on teaching of PC and smartphone hardware assembly, especially in environments where physical resources are limited. This challenge is critical because practical learning in hardware is essential for developing technical skills in engineering students and related fields. Traditional alternatives, such as simulators or online tutorials, have not managed to provide an immersive and efficient learning experience. To address this need, Build_3D was developed—a mixed reality (MR) application designed for learning PC and smartphone hardware assembly, experienced through the Meta Quest 3 headset. The use of MR in an educational context is a topic of considerable debate, given the necessity for a comprehensive analysis of its potential advantages and disadvantages. This research proposes an evaluation of Build_3D's usability using the Computer System Usability Questionnaire (IBM-CSUQ), focusing on three key dimensions: interface quality (INTERQUIAL), information quality (INFOQUIAL), and system usability (SYSUSE). The results indicate high user satisfaction, with interface quality rated the highest, followed by information quality and system usability. These findings suggest that this application provides an immersive and effective educational experience, minimizing cognitive load without compromising the quality of practical learning. The implications of this solution point to an improvement in hands-on hardware teaching through MR technologies, offering a viable and scalable alternative in educational environments with limited access to physical labs. Finally, this facilitates autonomous and motivating acquisition of technical skills for students.

INDEX TERMS Mixed reality, PC hardware education, usability evaluation, IBM-CSUQ, user satisfaction, meta quest.

I. INTRODUCTION

In recent decades, the evolution of digital technologies has radically transformed nearly every aspect of society, including entertainment, communication, healthcare, and especially education [1], [2]. As technological tools have become more accessible and advanced, their integration into educational processes has created new opportunities to enhance the learning experience, making it more interactive, personalized, and immersive [3]. Among these technologies, mixed reality (MR) has emerged as one of the most promising innovations, combining the benefits of virtual reality (VR) and augmented

The associate editor coordinating the review of this manuscript and approving it for publication was Martin Reisslein.

reality (AR) to create environments where the physical and virtual worlds merge, allowing users to interact with both in real time [4], [5], [6].

Over the past few years, the incorporation of digital technologies in education has accelerated significantly [7]. The advent of online learning platforms, such as Moodle and Blackboard, marked the beginning of large-scale digital learning [8]. These platforms provided students with access to educational materials and enabled remote interaction with teachers and classmates, democratizing access to education globally [8]. Later, with the rise of mobile devices, learning became even more accessible through educational applications and the use of tools such as massive open online courses (MOOCs) [9], [10]. However, although these technologies improved access to information and learning flexibility, challenges remained in terms of practical interaction and personalization of the educational experience, especially in fields that require a hands-on approach, such as engineering, medicine, and applied sciences [11], [12].

MR is a technology that combines elements of VR and AR [13]. VR creates fully immersive environments that transport users to digitally generated worlds [14]. Meanwhile, AR overlays digital information onto the real physical environment, allowing users to view and interact with virtual elements in their physical space [15]. MR, therefore, merges these two technologies, enabling users to simultaneously interact with virtual and physical objects in a unified environment [16].

The evolution of MR has been driven by advances in graphics processing capacity, the development of lighter, more ergonomic devices, and improvements in natural interaction systems, such as eye tracking, gesture recognition, and voice commands [17]. Devices like the Microsoft HoloLens and Meta Quest 3 represent some of the most advanced developments in MR, allowing users to experience a world where the physical and digital blend seamlessly [18].

The application of MR in engineering education holds significant potential, yet it remains relatively underexplored compared to its use in fields like medicine, fundamental sciences, and sports. As MR has matured, its use has expanded across various sectors. In industry, for example, it is used to simulate complex processes, train workers in hazardous tasks, or perform remote maintenance with real-time visual guides [19]. In medicine, MR has been employed in surgery planning and medical student training, allowing them to practice complex procedures in highly realistic simulations without putting patient lives at risk [20]. Another key application area has been entertainment, where MR is used to create immersive experiences in video games, movies, and interactive events [21], [22], [23]. These experiences are not only entertaining but can also have educational applications, allowing users to learn through simulation and interaction with previously inaccessible content [24], [25].

In education, MR has proven to be a powerful tool for transforming and innovating learning [26]. MR enables students to experience abstract concepts in tangible ways, which is especially beneficial in areas such as engineering, natural sciences, and medicine [27], [28], [29]. For example, in teaching chemistry, MR can allow students to manipulate subatomic particles in a virtual environment, helping them understand phenomena that would otherwise be difficult to visualize [30], [31]. One of MR's main advantages in education is its ability to create immersive and personalized learning environments [32]. Through interaction with objects, students can learn at their own pace, repeating procedures or experiments as many times as necessary without the limitations of physical resources [33].

The value of MR in engineering extends beyond traditional instructional methods by enabling students to interact with virtual models of complex equipment [34]. This approach not only reduces the need for physical components but also minimizes the risk of equipment damage—a common issue in hardware labs where students handle sensitive, expensive devices [35], [36]. By reducing the risk of damage, MR also fosters a more confident, exploratory approach to learning, as students can experiment freely without fear of breaking real components [35]. Additionally, MR enables a more practical approach to learning, something difficult to achieve with other educational technologies [37]. The immersive environments created by MR not only enhance knowledge retention but also increase student motivation, as they are more engaged when actively interacting with content [38].

In this context, the Build_3D MR application, developed for the Meta Quest 3 headset, represents an innovative solution for learning PC and smartphone hardware assembly. Build_3D allows students to interact with three-dimensional models of hardware components in a mixed environment, combining virtual objects with the physical environment. Students can assemble and disassemble hardware without the need for costly equipment or physical labs. Using Build_3D not only reduces dependence on physical resources but also offers the possibility of repeating complex procedures as many times as necessary, significantly improving the acquisition of practical skills. Furthermore, the ability to work in a safe and controlled environment minimizes the risk of damaging expensive components, a common concern in traditional hardware labs. However, despite these advantages, there is a pressing need to assess the usability of MR tools like Build_3D in educational settings to ensure they effectively support meaningful learning outcomes. The usability of such applications is crucial, as a poorly designed interface or overly complex interactions could hinder students' understanding and reduce engagement, ultimately impacting their ability to successfully learn and apply complex assembly and operation skills.

Therefore, this research aims to analyze the usability perceived by students when using Build_3D as a support tool for teaching the operation and assembly of technological equipment, seeking to determine if it enables a productive and immersive learning experience. This application was specifically developed to motivate students in acquiring the skills necessary to understand the operation and components of PC and smartphone hardware. The objectives of this research were:

Objective 1: Analyze the usability perception experienced by students when using Build_3D as an educational support tool.

Objective 2: Identify the perceived utility of Build_3D as an educational support tool.

To measure the effectiveness of learning to use Build_3D, it is essential to evaluate its usability from the students' perspective. In this study, the Computer System Usability Questionnaire (IBM-CSUQ) was used, a widely accepted standard for measuring user satisfaction in terms of three key dimensions: interface quality (INTERQUIAL), information quality (INFOQUIAL), and system usability (SYSUSE). These dimensions provide a comprehensive view of the user experience when interacting with the application and allow areas for improvement to be identified. The results of the Build_3D usability evaluation were highly positive, indicating that the system meets the functional requirements to facilitate the intended learning.

In this section, the reader is introduced to the research topic. The following sections of this paper are organized as follows: Section II reviews the application of MR technology in education. Section III details the research methodology employed. Section IV presents the research findings. Section V discusses these results in depth. Section VI outlines the study's conclusions, and Section VII suggests directions for future research.

II. RELATED WORK

In recent years, MR technology has gained ground across various sectors, particularly in education [39]. MR allows students to interact with both virtual objects and their physical environment, creating unique opportunities for experiential learning [4]. From elementary to higher education, this technology has been applied to teach complex concepts in an interactive and immersive manner [40]. As MR devices, such as the Microsoft HoloLens and Meta Quest headsets, have evolved and become more accessible, their use in educational settings has significantly increased [18].

Several studies have shown that MR can improve knowledge retention, increase motivation, and facilitate the understanding of abstract concepts [5], [41]. Immersion transforms passive learning into active engagement, deeply involving students in the content [42]. Furthermore, the ability to manipulate virtual objects in real-time allows a more tangible understanding of the topics being studied, which is especially useful in disciplines such as science, engineering, and medicine [43], [44], [45], [46]. MR demonstrated that the portability of devices positively influences perceived ease of use and utility for hands-on learning in crime scene analysis [4].

Likewise, MR technology has been successfully applied to innovate the teaching of engineering subjects. The research conducted by Sahin et al. [34], enables students to visualize connections between wireless nodes, antenna radiation patterns, and data performance in wireless networks. These immersive environments allowed testing different configurations and analyzing the behavior of communication systems in real-time without the need for physical laboratories. This type of practice not only reinforces theoretical concepts but also minimizes the risk of costly errors in physical environments [34], [47].

In this context, Wu et al. [48], explore how MR technology can help bridge the skills gap in the construction and engineering industry by facilitating the learning of tacit knowledge and improving the transition of university students into the workplace. Through a case study in a timber structure construction laboratory, the performance of student groups using MR visualization technology was compared to a control group working with traditional paper drawings. Preliminary results suggest that MR enhances students' understanding of design and the skills necessary for constructing structures, providing a basis for future research in this area.

Martín-Gutiérrez et al. [49], analyze the validation and usability of an MR application designed to develop spatial skills in first-year engineering students. The results were compared between students using head-mounted hardware versus PC monitors. The findings confirm the validity of the training and suggest improvements in the interface and educational materials, highlighting the effectiveness of MR in improving academic performance.

Tumkor [50], discuss how MR applications personalize engineering education, particularly in geometric visualization. Students with visualization problems benefited from MR technologies that allow them to observe and manipulate 3D models. Mental rotation tests, conducted before and after training, showed improvements in visualization skills, suggesting that a background in video games influences the level of benefit obtained from MR technologies.

Richert et al. [51], explore the use of MR-based games in engineering education, proposing a diversified and experience-oriented learning environment. The design of these games enables the integration and practice of technical and methodological topics in a collaborative and applied learning setting.

Aziz et al. [52], developed an MRI and VR system to enhance education and training in engineering assembly processes. The system, tested with university students, showed improvements in comprehension and psychomotor skills, demonstrating that MRI can be adopted as an effective learning method for training in maintenance and assembly of machine parts.

Müller et al. [53], present a collaborative learning space that combines real, virtual and remote tools, facilitating collaborative experimentation in engineering education. In addition, they discuss concepts related to the use of RM technology and identify future research to improve remote collaborative work in engineering education.

Suhail et al. [54], systematically review the use of MR in engineering education, highlighting its educational impact and identifying areas for improvement. Their findings show that the use of this technology can enhance visualization, interaction, and student motivation in disciplines such as civil and mechanical engineering. Although its adoption in other areas is limited, they recommend addressing technical challenges and improving curricular integration to maximize the educational benefits of MR.

MR solutions offer significant benefits in education, such as increased motivation for learning and self-learning through direct interaction with virtual components, surpassing traditional teaching approaches [16]. Furthermore, MR enhances the development of spatial and psychomotor skills by allowing students to visualize and manipulate 3D models [55]. It has also been demonstrated that the use of MR as an educational aid increases student engagement and participation compared to traditional methods due to its more interactive and immersive experiences [56]. However, MR solutions have limitations, including the high cost of hardware, technical challenges in system integration, and potential physical discomfort due to prolonged use of MR glasses.

Traditional teaching is more affordable and easier to implement, outperforming MR in terms of cost and logistical simplicity. Additionally, it does not require advanced technical knowledge nor does it present physical discomfort issues such as dizziness or eye strain, which are common in MR environments. However, compared to MR, traditional methods lack the immersion and interactivity needed to develop complex spatial skills or simulate advanced assembly scenarios, which may limit student engagement and long-term knowledge retention.

III. METHODOLOGY

An MR application called Build_3D was designed to teach topics related to PC and smartphone hardware. This application effectively addresses pedagogical needs by providing a practical, dynamic, safe, and accessible learning environment that enhances students' theoretical and practical understanding.

A. BUILD_3D DESIGN

1) DESIGN PROCESS

The project was born from the idea of building a tool focused on learning about the components and assembly of hardware, such as a computer and a smartphone, using MR technology. To achieve this goal, two challenges had to be overcome with innovation and creativity. The first challenge was the assembly process for the elements (PC and smartphone), and the second was designing an interface that provides an optimal user experience. The application enables users to take components and assemble them correctly with natural interactions, meaning minimal friction and as closely resembling real-life actions as possible. The natural approach allows users to manipulate objects, position them, release them, or rearrange them using hand gestures like "grabbing" and "releasing". To accomplish this, customized software and code were utilized, leveraging the integrated cameras in Meta Quest 3 to detect hand silhouettes, finger positions, curvature, flexion, spacing between fingers, and opposition. Figure 1 shows the four positions that fingers can assume, designed to create an MR application suitable for its intended use and functionality.

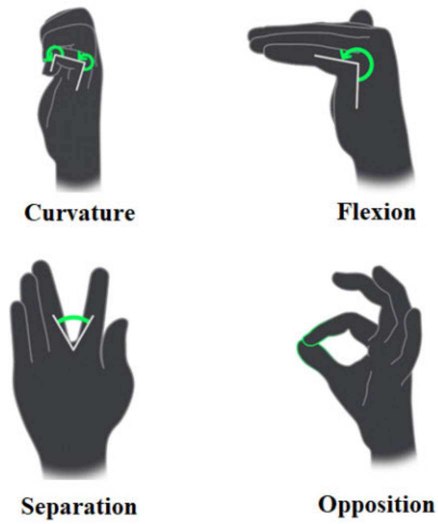

FIGURE 1. Finger position for interacting with 3D objects in MR environments.

Curvature detects how curled the fingers are based on their joints. Flexion detects the angle at which the knuckles bend toward the palm. Spacing relative to other fingers identifies when adjacent fingers are separated, forming an angle. Finally, opposition detects the proximity of a fingertip to the thumb, applied specifically to the index, middle, ring, and little fingers. Two main points are proposed for MR software development:

- 3D Objects. These are placed in the scene to prompt an action based on familiar real-world object usage. For example, using a red button indicates to the user that interacting with this 3D element requires pressing it, after which an expected outcome will occur. This is especially important for novice MR users.
- Spatial Text. The application includes a feature that displays detailed information about each component in text form. The user can handle the text as a 3D object to read it, but upon releasing it, it might be positioned at an awkward angle or even rendered invisible.

To address this issue, a text-tracking system was implemented, allowing the text to track both the object and the user's position.

2) REQUIREMENTS

To design a MR application for the Meta Quest 3, it is essential to consider a series of design requirements that ensure an immersive, intuitive and efficient experience for the user [49], [57]. The development focused on both the educational perspective and the user experience. As shown in Table 1, several requirements must be met for the design of

TABLE 1. Design requirements for application usability.

Requirement	Description
Integration of the physical and virtual environment	Leveraging the high-resolution full-color external camera capabilities of Meta Quest 3 to seamlessly integrate virtual elements with the user's real-world environment. This enables the creation of a seamless and coherent mixed reality (MR) experience.
Intuitive User Interface	Interface design that is easy to navigate and understand, using clear visual elements and controls that take advantage of redesigned "Touch Plus" controllers for natural interaction.
Convenience and Optimizations	Application design that prevents dizziness due to low visual quality or performance drops, code, execution and resources are optimized by: ● Optimized looping and search programming. ● Dynamic management of active or inactive elements based on the activity, where each element has its own physics and responds to these interactions defined by scripts. ● 3D elements with polygon reduction and detail balancing techniques ● Software rendering, graphics, lights and shadows balanced for better performance.
Comfort and Ergonomics	Interaction design through hand gestures, hand position detection and similar human-computer interaction techniques to reduce user friction. To indicate that a PC component is positioned in a specific location, when the user grasps the component, a hologram displays the correct location and alignment for that component. This is accomplished through "Shaders," which are programs that instruct the device chip how to render pixels. This allows effects such as holograms, transparencies, metallic reflections, among others.
Accessibility	Design that allows users with different disabilities to interact with the application, including adjustable text sizes, alternative control options, and inclusive design considerations.

the MR application. These include integration of the physical and virtual environment, an intuitive user interface, optimization, comfort, ergonomics, and accessibility [50], [52]. In addition, Table 2 presents the technological tools used, and Table 3 details the specific libraries and dependencies used for the design of Build_3D.

3) DEVELOPMENT METHODOLOGY

The SCRUM methodology was employed due to the project's nature, which required incremental progress to test interactions during the development phase. Six iterations were defined over six weeks, given the team's knowledge and proficiency with the technologies used.

4) BUILD_3D APPLICATION VISUALIZATION

Figure 2 provides a detailed visualization of the disassembly process of a PC and a smartphone. The background displayed in these figures is an example of the ability to use MR ubiquitously, this academic support can be used in the classroom or outside the classroom. In these figures Build_3D uses MR to show key internal elements such as the battery, the motherboard, the camera module or the haptic engine, among others. This detailed segmentation allows users to see each component in its physical context, facilitating interactive learning about PC and smartphone hardware. Figure 2 shows that users can interact directly with device components, simulating actions such as removing the motherboard. This suggests that the application promotes a hands-on, immersive approach, which can improve information retention and motivation in learning. Direct manipulation of components in MR space represents a significant advance over traditional teaching methods, such as textbooks or 2D simulations.

In each scene, floating information panels are used to explain the hardware components. The texts provide technical descriptions of the purpose and characteristics of each component. This accessible presentation allows students to learn at their own pace, providing a personalized educational experience. The application is scalable in terms of the types of devices that can be disassembled, suggesting that it can be extended to other hardware or electronic devices, which would provide versatility for different training areas. Additionally, as seen in Figure 2 there is a mechanism (a red button) that can be pressed to switch between the visualization of a smartphone and a PC, highlighting a key feature in the design of Build_3D, which is its ability to teach various types of hardware technology. This shows that the application can be adjusted to different levels of knowledge, covering both simple components and more complex systems like those in a PC.

5) BUILD_3D USAGE AND SEQUENCE

The sequence diagram for using Build_3D is outlined as follows. The components "InfoFollowComponent.cs", "Initialization" and "Follow Component and Face Camera" ensure that each component's information follows its respective object in a 3D environment, maintaining the front face of the text always visible to the player. After initialization, the main camera is verified and assigned to track the player's view. During execution, the information text is adjusted in real time to remain aligned to the front of the

TABLE 2. Technological tools.

Technology Name	Description	Use
Unity 2022.3.10f1	Versatile game engine with features for building 2D, 3D, VR, AR, and MR projects with export capabilities to multiple platforms, including Mobile devices, Web, among others. It allows programming with components called "Scripts" written in C#. The following base configuration was used: ● Export platform: Android ● Texture compression: ETC2 (GLES 3.0) ● Compression method: LZ4 ● Render pipeline: Built-in	The following steps were performed for the **creation, editing, and compilation** of the project, leveraging essential tools and configurations: ● Creating a new 3D project in Unity using the Built-In Render Pipeline configuration. ● Installing Meta libraries and dependencies from the Package Manager to access development components compatible with the Meta Quest 3 hardware. ● Integrating required 3D elements exported from Blender into the project's file system. ● Extracting and assigning materials and textures to the imported 3D elements. ● Building the scene with a structured component toolbar. ● Assigning scripts written in C# (developed in Visual Studio Code) to corresponding GameObjects or project elements according to their function and responsibilities. ● Testing general functionality using Unity's **"Play" mode**. ● Modifying export settings to configure Android as the target platform and applying LZ4 compression with the ETC2 texture format. ● Executing the Build process to compile the project and generate an installable APK for the Meta Quest 3.
Visual Studio Code	Source code editor developed by Microsoft for Windows, Linux, macOS, and Web. Visual Studio Code was chosen for being lightweight and highly customizable. Extensions used: ● Unity: Integrated development experience and C# Dev Kit for Unity projects ● IntelliCode for C# Dev Kit: Includes assistance for C# development ● C#: Support for C# language development ● C# Dev Kit: Solution explorer and testing management	It was used for the creation of scripts (code) in the C# programming language, the scripts together orchestrate the logic of the project. In addition, it also serves to: ● Generally manage the project logic. ● Verify object states (placed, not placed, user attached or loose). ● Activate and deactivate additional information for each component ● Verify component assembly order ● Manage scenes to navigate between the PC and mobile device scene
Blender 3.3.21.0	Free, open-source 3D modeling software used for: ● Construction of necessary elements ● Optimization and retopology: Techniques to reduce polygon count for a smoother experience	It was used for pre-processing and optimization of the mesh (geometry in terms of polygons) of 3D objects. In addition, it also serves to: ● Import/create 3D FBX and OBJ files based on blender. ● Apply retopology as an optimization technique to reduce the number of polygons building the 3D mesh of objects. ● Verify that the retopology did not affect materials and textures ● Correct materials and textures applied on the 3D geometry ● Build maps if necessary to apply materials and textures correctly after retopology ● Export 3D models in OBJ or FBX format with textures and materials included

player, ensuring that the text is always legible and visible. The "MainboardVerification.cs", "Mainboard Placement" and "Mainboard Removal" components guarantee that the mainboard, in the simulation, is correctly positioned before

TABLE 3. Libraries and dependencies used.

Technology Name	Description	Use
Meta MR Utility Kit	Utilities and tools at the API scene level to execute operations dependent on the spatial component of the physical space. https://developer.oculus.com/documentation/unity/unity-mr-utility-kit-overview	**Meta XR All-in-One SDK** was used for **importing and installing dependencies** together with other components. It was also used to **initialize project execution**, creating and positioning **3D elements** based on a **local coordinate system** that depends on the **initial position of the Meta Quest 3 device**.
Meta XR All-in-One SDK	Set of all Meta SDKs including features from advanced rendering, social functions, support for building immersive virtual and mixed reality experiences. Includes: ● Meta XR Core SDK (https://developer.oculus.com/downloads/package/meta-xr-core-sdk) ● Meta XR Audio SDK (https://developer.oculus.com/downloads/package/meta-xr-audio-sdk) ● Meta XR Haptics SDK (https://developer.oculus.com/documentation/unity/unity-haptics-sdk) ● Meta XR Interaction SDK Essentials (https://assetstore.unity.com/packages/tools/integration/meta-xr-interaction-sdk-essentials-264559) ● Meta XR Interaction SDK (https://developer.oculus.com/downloads/package/meta-xr-interaction-sdk-ovr-integration/) ● Meta XR Platform SDK (https://developer.oculus.com/downloads/package/meta-xr-platform-sdk/) ● Meta XR Voice SDK (https://developer.oculus.com/downloads/package/meta-voice-sdk) ● Meta XR Simulator (https://developer.oculus.com/downloads/package/meta-xr-simulator) ● Meta Mixed Reality Utility Kit (https://developer.oculus.com/downloads/package/meta-xr-mr-utility-kit-upm)	It was used to import from the Unity package manager. In addition, upon installation, it installs all the dependencies and libraries related to the Meta SDKs for the development of virtual or augmented reality projects from Unity for Meta Quest family hardware. Upon completion of its installation it creates folders in the project file system for all dependencies included in the bundle such as Utility Kit, Core SDK, Audio SDK, Haptics SDK, Interaction SDK Essentials, Interaction SDK, Platform SDK, Voice SDK, XR Simulator, Mixed Reality Utility Kit. Links all resources, scripts and 3D models together with all installed Meta-related dependencies to prevent errors when using the SDK.
Meta XR Audio SDK	Provides spatial audio features for immersive applications.	It was used, together with the Meta XR All-in-One SDK, to ensure the functionality of the dependency bundle. Additionally, it provides access to spatial audio configuration if this feature is utilized.
Meta XR Core SDK	Provides the latest features to create immersive experiences for MR devices, such as Passthrough, Anchors, and Scene Understanding.	It was used to install and enable passthrough, allowing users to view reality while using mixed reality (MR). Additionally, it imports the initial camera configuration and sets it up with passthrough access, enabling the use of mixed reality instead of virtual reality (VR).
Meta XR Interaction SDK	Provides the core implementation of interaction models along with shaders, materials, and necessary prefabs	It was used to enable the interaction core, as well as to import the shader, material, and texture applied to the geometry for rendering the user's hands.

TABLE 3. ***(Continued.)* Libraries and dependencies used.**

		With the help of this tool, custom gestures are configured along with their corresponding actions to allow users to grab and release objects. In this context, this tool defines which hand and finger positions will trigger an action, such as grabbing an object. This functionality is essential for applying position and rotation transformations to objects based on hand-tracking gestures.
Meta XR Simulator	Allows visualizing changes in the project without needing a physical device or building the project.	It was used to test the project during development. With Meta XR Simulator enabled, the project runs in Unity's Play mode, creating a Meta Quest hardware emulator where the project is executed. In this context, the keyboard and mouse are used to simulate hand movements and actions, such as grabbing objects within the simulator, allowing for interaction testing and debugging throughout the development process.
Oculus XR Plugin	Provides support for input reception and display of information for Oculus devices.	It is used to apply project settings on the correct use of the rendering API especially in virtual/mixed reality projects on Meta Quest hardware. Moreover, it maps correctly the tracking of sensors, buttons and gestures of Meta Quest family devices in the Unity system, allowing to access and modify, through code, these configurations.
XR Plugin Management	Provides simple management of extended reality (XR) plugins. Manages and offers loading assistance, initialization, configuration, and build support.	It was used to configure and manage the XR provider plugins (low-level configurations to support Mixed Reality technologies) in the Unity project targeting the Meta Quest family specifically.

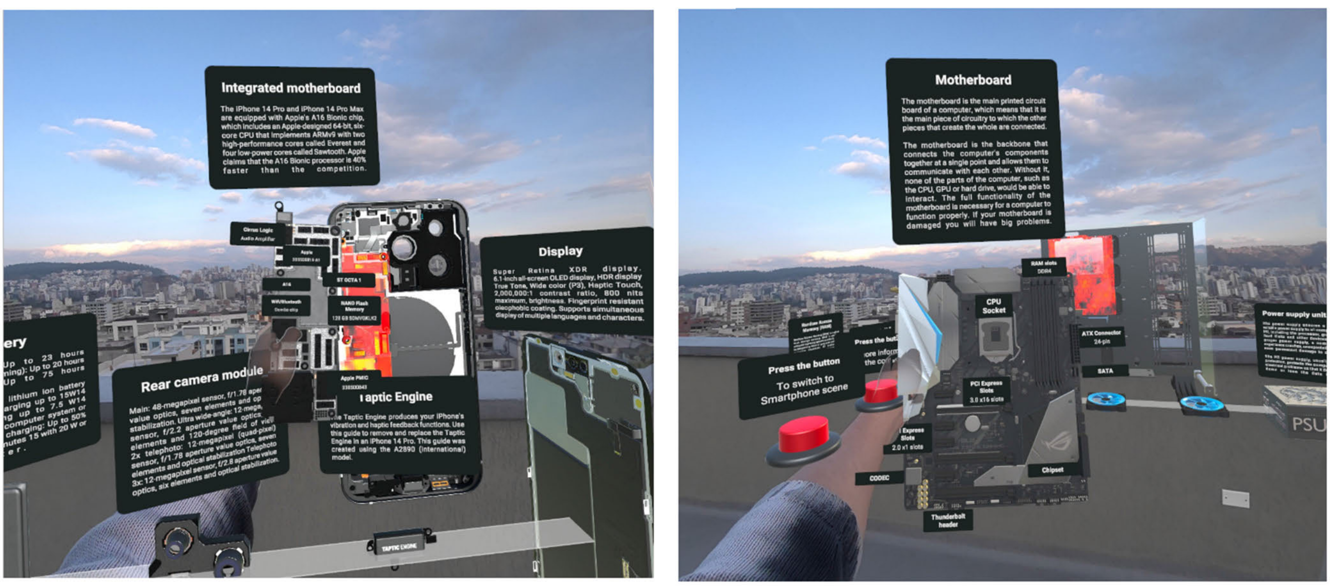

FIGURE 2. **Handling hardware components in Build_3D (Left: smartphone components, right: PC components).**

allowing the installation of its internal components. This ensures that the assembly process continues only if the mainboard is properly installed.

The components "ShowInfoManager.cs", "Start and Setup:", "Deactivating Information:", "Activating Information:", "Toggling Information:" provide an overview of the

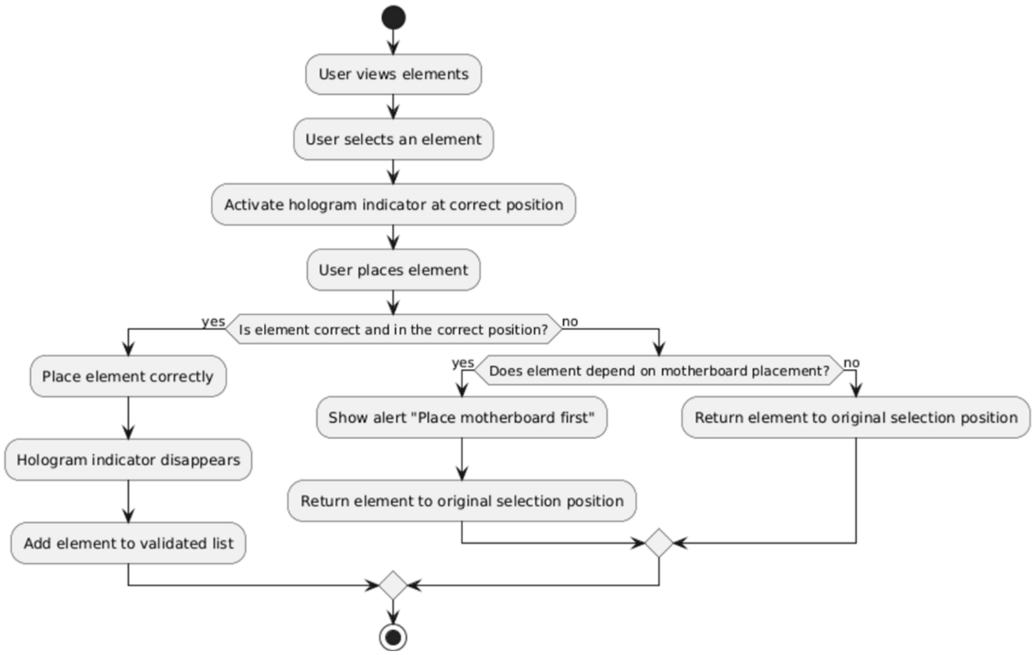

FIGURE 3. **Build_3D user activity diagram.**

methods and their effects on the assembly flow, which helps to understand the process and dependencies between the components and the mainboard. These components prepare the initial state of the system, activate the information of all components, making the details visible to the user. Finally, the information is activated when the player presses the "Information" button.

The components "SnapManager.cs", "Start and Setup:", "Component Placement with Mainboard Requirement:" and "Updating All Slots:" enable assembly and help to understand the process and dependencies between components and the mainboard. They also manage the assembly of components that depend on the mainboard. In case the assembly is not yet complete, a warning message is displayed: "You must attach the mainboard before attaching this component". In addition, it serves to deactivate all slots for objects that require the "mainboard".

The "ShowInfoManager.cs", "Start and Setup:", "Deactivating Information:", "Activating Information:", "Toggling Information:" components manage the assembly of components, ensuring that "the mainboard" is in place before allowing the installation of other components. They also manage the display of detailed component information, allowing information to be enabled, disabled or toggled based on user actions.

The "ShowHologramHint.cs", "Start and Setup:", "Object Enters Zone:", "Object Stays in Zone:", "Object Exits Zone:" components provide a holographic visual reference to guide the user in the correct assembly of PC components. During interaction, the holograms are activated when components enter the detection zone, verifying if they are correctly aligned, and deactivates the hologram when components exit the detection zone. The system also handles collision validation and ensures that components are mounted in the correct location.

The use of all these components allows the application to be simple to use and students have no extra cognitive load when using Buil_3D to support their education. Figures 3 and 4 show the sequence and usage diagrams of Build_3D in which the simple use of this educational application can be observed.

B. BUILD_3D USABILITY EVALUATION

Unlike similar initiatives in the current literature, this research did not focus solely on the design aspects and results of using Build_3D. Instead, the objective of this study is to evaluate the usability of Build_3D. To achieve this, the IBM-CSUQ tool, which measures user satisfaction regarding the use of Build_3D [58]. The IBM-CSUQ is an established tool for assessing the quality and effectiveness of interactive systems from the user's perspective. Its application in this study provides detailed insight into how users perceive the usability and usefulness of the application.

1) PARTICIPANTS

This research involved the participation of 50 students from a higher education institution. All students agreed to informed consent provided through a web form. Participants were selected through convenient sampling. Of the 50 participants, 22 were women (44%) and 28 were men (56%).

2) TASK

The experiment began with an introduction to using the Build_3D application. Participants had the opportunity to ask

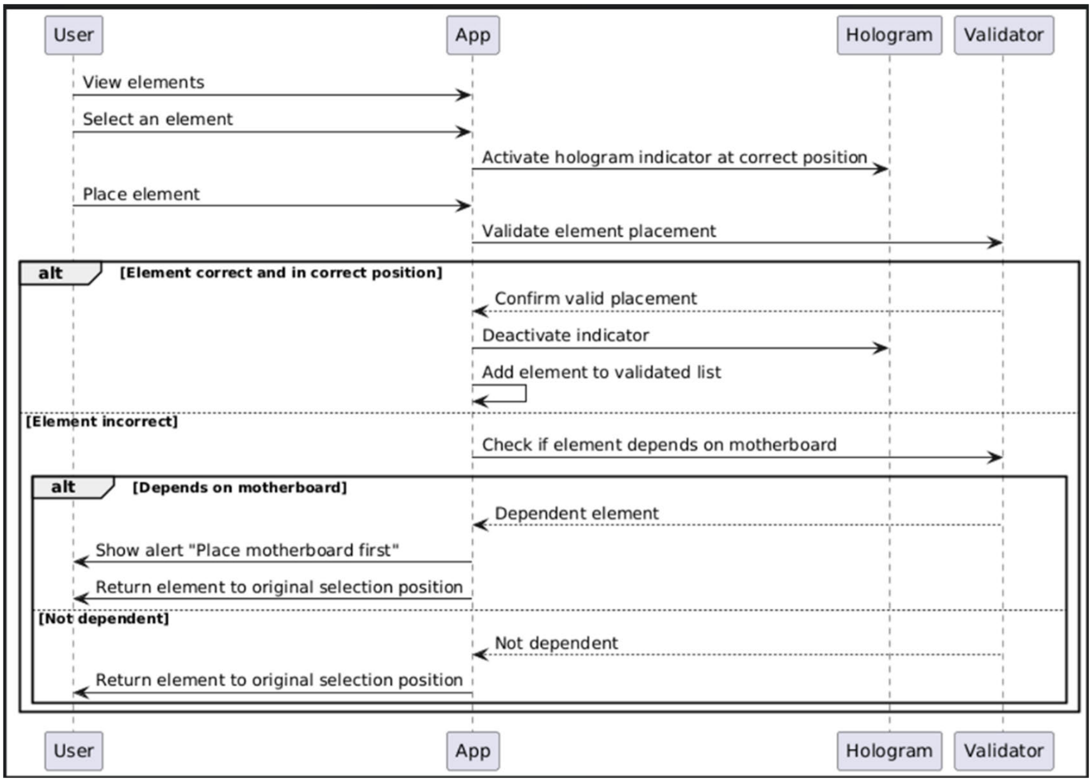

FIGURE 4. **Build_3D sequence diagram.**

questions and provide feedback and recommendations on the designed application:

Students used Build_3D; each participant spent approximately 10 minutes assembling the PC and 10 minutes assembling the smartphone.

Students completed the IBM-CSUQ questionnaire. The information gathered helped assess their perception of the usability of MR technology as a support tool in higher education.

Additionally, students responded to a survey designed to identify the application's usefulness and their recommendation for its use.

These data can be valuable for educators and educational institutions seeking to incorporate MR to innovate traditional methodologies and adequately address current challenges in the learning process.

3) USABILITY ANALYSIS

To evaluate the usability of Build_3D, a survey based on the IBM-CSUQ tool was used, employing a 7-point Likert scale [58], [59]. This questionnaire consists of 19 questions designed to measure user satisfaction with the developed application [59]. The survey aims to gather data on various aspects, such as system usability (SYSUSE), the quality of information provided (INFOQUIAL), interface quality (INTERQUIAL), and an overall assessment of the application and its ease of use (OVERALL). The questionnaire questions are presented below:

Questions SYSUSE (QSY)

Q1 Overall, I am satisfied with how easy it is to use this system.
Q2 It is simple to use this system.
Q3 I can effectively complete my work using this system.
Q4 I am able to complete my work quickly using this system.
Q5 I am able to efficiently complete my work using this system.
Q6 I feel comfortable using this system.
Q7 It was easy to learn to use this system.
Q8 I believe I became productive quickly using this system.

Questions INFOQUIAL (QIF)

Q9 The system gives error messages that clearly tell me how to fix problems.
Q10 Whenever I make a mistake using the system, I recover easily and quickly.
Q11 The information (on-screen messages and guidance or other documentation) provided with this system is clear.
Q12 It is easy to find the information I need.
Q13 The information provided with the system is easy to understand.
Q14 The information is effective in helping me complete my work.
Q15 The organization of information on the system screens is clear.

Questions INTERQUIAL (QIT)

Q16 The interface of this system is pleasant.
Q17 I like using the interface of this system.
Q18 This system has all the functions and capabilities I expect it to have.

Question OVERALL (QOV)

Q19 Overall, I am satisfied with this system.

4) PERCEIVED USEFULNESS ANALYSIS

When designing an educational application, it is not only crucial for it to function effectively but also for users to consider it potentially useful as a support in their educational process. For this reason, a survey was used to measure the perceived usefulness of Build_3D as a complementary tool in teaching PC and smartphone hardware. The questions used in the survey, based on the research by Criollo-C et al. [2], are as follows:

QA Do you think this application is applicable in classrooms to motivate learning about PC hardware and smartphone?
QB Do you think this application gives students an interesting insight into the parts of a PC and smartphone?
QC Would you use this application in your classroom?
QD Do you think that using this application improves your learning?
QE Do you consider this application as an effective tool for guided learning in class?
QF Would you recommend this application as an educational tool in the classroom?

This survey also includes a multiple-choice question. After using the application, participants were asked to choose a word that describes their perception of its use from the following options: useful, entertaining, easy to use, friendly, motivating, intuitive, or prefer not to answer.

IV. RESULTS

A. USABILITY ANALYSIS

Table 4 presents the mean, standard deviation, and median results for the four categories of the IBM-CSUQ tool. This table provides insight into the central tendency and variability of responses across different usability dimensions. Table 5 displays the maximum, average, and minimum values obtained from the usability analysis tool. These data points help to identify the range of user perceptions regarding the mixed reality (MR) application for PC and smartphone hardware practice using the Meta Quest 3 headset. Figure 5 graphically illustrates the results from the previous tables, facilitating a comparative visualization of the top, average, and bottom values in each usability category.

Additionally, Figures 6 and 7 respectively show the responses of the 50 participants, grouped by gender (male and female). These charts allow for an analysis of how each group experiences the usability of the Build_3D application. Additionally, potential differences between genders regarding the perception of usability as an educational support tool could be crucial for a comprehensive interpretation of the results.

TABLE 4. Mean (μ), Standard Deviation (σ) and Median (M) Survey across all participants.

IBM-CSUQ	Question	μ	σ	M
SYSUSE	Q1	5.68	6	0.51
	Q2	5.74	6	0.78
	Q3	5.88	6	0.63
	Q4	5.76	6	0.59
	Q5	5.68	6	0.74
	Q6	6.12	6	0.72
	Q7	6.06	6	0.77
	Q8	5.54	5	0.65
INFOQUIAL	Q9	5.44	6	0.86
	Q10	5.56	6	0.95
	Q11	5.44	6	1.05
	Q12	5.80	6	0.86
	Q13	5.36	5	0.75
	Q14	5.42	5.5	0.97
	Q15	5.74	6	0.72
INTERQUIAL	Q16	6.12	6	0.66
	Q17	6.06	6	0.62
	Q18	6.04	6	0.75
OVERALL	Q19	6.54	7	0.50

TABLE 5. Top, Average, Botton, and minimum values obtained with the usability analysis tool.

	QSY	QIF	QIT	QOV
Top	6.07	6.09	6.53	7.04
Average	5.81	5.54	6.07	6.54
Bottom	5.55	4.98	5.62	6.04
Median	5.81	5.64	6.00	7.00
Standard Deviation	0.26	0.56	0.45	0.50

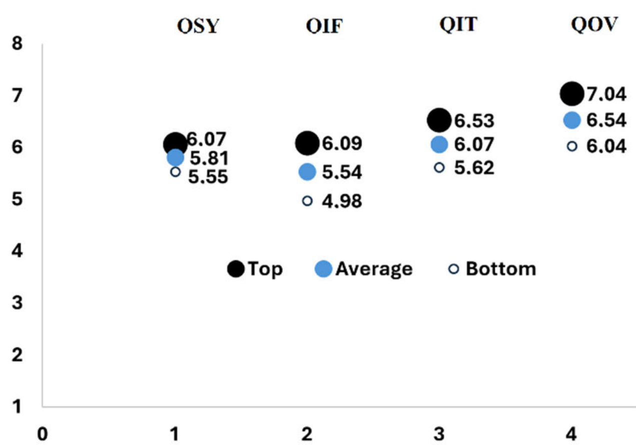

FIGURE 5. General results of the IBM-CSUQ survey.

These visualizations contribute to a deeper understanding of the data, highlighting key aspects of the user experience in the educational context with emerging technologies.

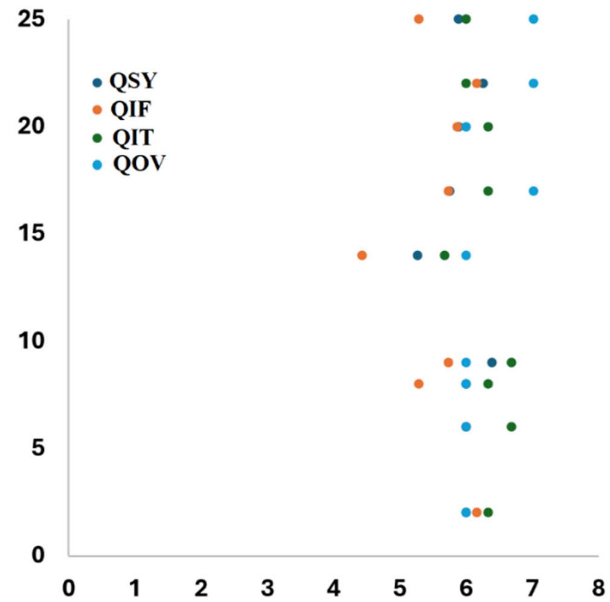

FIGURE 6. Response of participants in the IBM-CSUQ survey (Male).

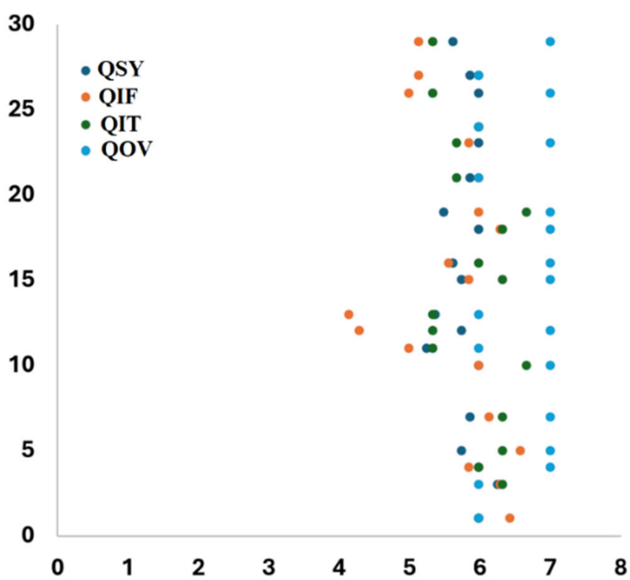

FIGURE 7. Response of participants in the IBM-CSUQ survey (Female).

B. PERCEIVED USEFULNESS ANALYSIS

Figures 8 and 9 show all participants' perceptions regarding the usefulness and use of Build_3D as support within the educational model. Additionally, Figure 9 presents the words chosen by students to describe the application. Most students perceive the application as useful and easy to use, which is a positive indicator that the tool is fulfilling its educational purpose. This could suggest that Build_3D is effectively facilitating learning about PC and smartphone hardware.

V. DISCUSSION

A. OBJECTIVE 1

The IBM-CSUQ tool is a widely used and recognised tool in the field of usability. In this research, it is demonstrated to be effective, easy to use, comprehensive in scope, standardised, and adaptable [58].

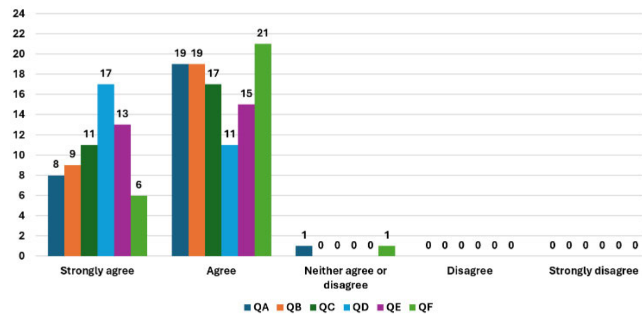

FIGURE 8. Answer to questions QA, QB, QC, QD, QE, and QF (Male).

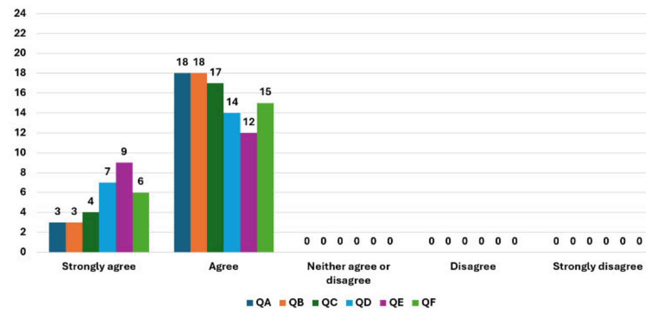

FIGURE 9. Answer to questions QA, QB, QC, QD, QE, and QF (Female).

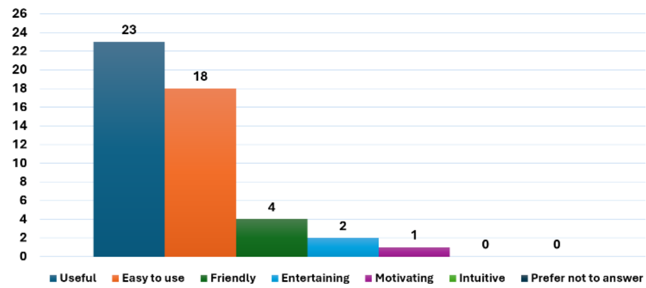

FIGURE 10. Using words to describe the application.

The usability study revealed a positive result. In the IBM-CSUQ survey, most participants responded ''agree'' or ''strongly agree'' to the questions posed. This can be seen in Table 4, Table 5, and Figure 4. The data presented shows that interface quality (INTERQUIAL: Q16 - Q18) has a positive trend, higher than usability (SYSUSE) and information quality (INFOQUIAL), both in maximum value (6.53) and average results (6.07). These values indicate that, when using Build_3D, students perceive high quality in the application's interfaces.

The quality of information presented in Build_3D (INFOQUIAL: Q9 - Q15) achieved the second-best results, with a maximum value of 6.09 and an average of 5.54. This suggests that Build_3D is designed in a way that allows students to interact with it intuitively and without difficulty. Furthermore, if the application displays useful and interesting information, it is highly likely that students will adopt it and be motivated to use it for their learning.

System usability (SYSUSE: Q1 - Q8) showed the lowest score among the four categories (SYSUSE, INTERQUIAL, INFOQUIAL, and OVERALL), with a maximum value of 6.07 and an average of 5.81. The lower usability experienced when using Build_3D could negatively affect user experience and reduce users' confidence in the application. These results suggest that the application's design can and should be improved in terms of usability and ease of use to enhance students' perceptions.

Finally, the overall satisfaction (OVERALL: Q19) results indicate that Build_3D was adequately perceived by students, with scores ranging from 6.04 to 7.04, most scores being close to the mean of 6.54, with a standard deviation of 0.5, indicating some variability in students' responses.

Question Q13, "The information provided with the system is easy to understand" (on-screen messages and orientation or other documentation), received the lowest score ($\mu = 5.36$). The low score in Q13 indicates that users found the information provided by Build_3D, whether in the form of on-screen messages, guidance, or additional documentation, was not entirely helpful in completing their tasks. This low score suggests a significant deficiency in terms of the support provided to users for effectively using the application. Addressing this issue by improving the quality, visibility, and relevance of information, as well as personalizing support, will be crucial to optimize user experience and learning effectiveness.

On the other hand, questions Q6, "I feel comfortable using this system", and Q16, "The interface of this system is pleasant," received the highest ratings ($\mu = 6.12$). The high score in Q6 shows that users feel a sense of familiarity when using the application. Additionally, the high rating in Q16 suggests that users found the application interface particularly attractive and enjoyable.

The high ratings in these questions underscore the success of Build_3D's interface in providing a visually appealing and pleasant experience for users. This positive aspect of usability not only enhances overall satisfaction but may also positively influence engagement and learning effectiveness.

In terms of overall usability, the median value is 7, reflecting a generally favorable opinion of the system's usability. However, it is important to note that, while scores are consistent, some users may have experienced minor challenges in terms of ease of use or task execution efficiency. Additionally, it should be considered that using AR glasses suggests additional physical effort, which was evident in this research and should be considered when deploying MR technologies in the classroom.

B. OBJECTIVE 2

1) PERCEIVED USEFULNESS-STUDENTS

Most students (both men and women) gave a high score to the question about whether the application is applicable in classrooms to motivate learning about PC and smartphone hardware (QA). This suggests a positive perception regarding the motivational impact of the application. Furthermore, the score related to learning improvement also tends to be in a high range, reinforcing the idea that students consider Build_3D useful for their education (QE).

Questions related to the perception of the application as an interesting tool (QB) and its applicability in the classroom (QC) also show consistent responses in the 4-5 range. This indicates that students find the application offers an interesting view of PC and smartphone parts and would be willing to use it in the classroom.

Most students also consider the application an effective tool for guided learning and would recommend its use as an educational tool (QD) (QF). The high average values in survey responses reflect a strong acceptance of the application as a teaching aid.

In the question where students were asked to choose words that describe their perception of the application, the most common responses were "Easy to use" and "Useful". This highlights that students value the simplicity of the interface and the practical utility of the application. Additional responses such as "Friendly", "Motivating" and "Entertaining" also appeared, suggesting that the application has a positive impact not only on learning but also on the user experience.

When reviewing the data by gender, no significant differences were observed between the responses of men and women, indicating that the application is perceived similarly by both genders. However, some male students gave slightly higher scores regarding the perception of the application as "entertaining," while female students placed more emphasis on the application being "useful". Build_3D appears to be well-received by students, who consider it enhances their learning and is applicable in an educational setting. Ease of use and utility are the most highlighted aspects, while entertainment and motivational elements also play an important role in the user experience.

VI. CONCLUSION

One of the key advantages of using the IBM-CSUQ was its ease of implementation, as it allowed for the rapid and systematic collection of quantitative data. Another advantage or reason for using it should be that it is a mature instrument that has been widely validated by numerous studies. Additionally, the tool facilitated result analysis by providing a clear 1-to-7 scale for each item, enabling a detailed analysis of standard deviation and averages across different countries. This resulted in robust data supporting conclusions about the system's usability and acceptance.

The analysis of the four key factors for the Build_3D application reveals positive acceptance among students. This analysis suggests that the application is well-received but also identifies areas where student perception could be improved. Enhancements in these areas could help reduce variability in user experiences and further increase overall acceptance of the application.

The results show that Build_3D is perceived by students as a useful and efficient tool for teaching PC and smartphone hardware. Students highlighted the ease of use, the ability to become productive quickly, and the application's effectiveness in completing educational tasks. Although overall satisfaction is high, areas such as the clarity of error messages and access to certain information could benefit from improvements. In general, students recommend the application as an effective and valuable educational tool for practical hardware learning, and they appreciate its interface for its simplicity and functionality.

The research reveals that students perceive Build_3D as a useful and effective tool for supporting PC and smartphone hardware education. High scores in application recommendation, perceived usefulness, and learning improvement indicate that students consider the application to have a positive impact on their education. Furthermore, ease of use is a highly appreciated feature, ensuring that the application is not only pedagogically effective but also accessible and user-friendly. Although motivation and interest could be slightly improved, the overall perception supports the conclusion that Build_3D is a recommended tool among students and has significant potential for continued implementation in educational institutions.

VII. FUTURE WORK

Currently, this research focuses on a group of students with similar demographic characteristics (mainly 18-19 years old). Future work could include students from different educational levels (e.g., high school, more advanced levels such as graduate studies) or even different fields of study (not just PC and smartphone hardware) to explore the effectiveness of using MR technology in other educational contexts.

It would also be interesting to conduct comparisons between different educational institutions, both nationally and internationally, to verify if the perceived utility of the application is consistent or varies depending on the region and the technological resources available in each educational environment.

Additionally, a longitudinal study could analyze whether students who use Build_3D retain the acquired knowledge better over time compared to traditional methods. This would involve a multi-phase evaluation, where students would be assessed again months after using the application to determine if it has a positive effect on long-term memory and the transfer of skills to real-world applications. Furthermore, it could be analyzed if students are able to transfer the knowledge acquired through Build_3D to problem-solving in real-life scenarios, such as the physical assembly of hardware. This could include conducting practical assessments in labs with real equipment.

Based on the feedback gathered in this research, the interface and usability of Build_3D could be improved, especially in areas where students identified opportunities for enhancement, such as information presentation and error message clarity. Future work could involve developing and testing a new version of the application with specific improvements and comparing the user experience before and after these changes.

Another potential avenue for future work could explore the integration of artificial intelligence (AI) to further enhance the learning experience. For instance, AI could adapt to the individual needs of each student, providing real-time personalized feedback.

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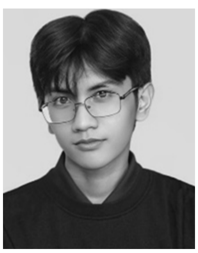

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