Development of Accessible Virtual Reality Technology for User Inclusion

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This research aimed to develop accessible hardware technology for virtual reality (VR), enabling its use across diverse environments and by a broader range of users. This approach aims to bridge the gap where technological advancements often become social barriers.We analyzed existing market technologies through an applied research method and designed a cost-effective, sustainable VR headset. The developed technology has been successfully validated, offering immersive interaction with VR environments while fostering innovation and creativity. However, particular challenges remain and present opportunities for further exploration. Future research will focus on optimizing the user experience, enhancing accessibility, and refining technological aspects to ensure a more inclusive and seamless VR interaction.
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Virtual Reality (VR) is a technology that simulates three-dimensional environments, allowing users to interact with these spaces in an immersive way. According to Tori and Hounsell (2018), VR creates experiences that transcend the physical world's limitations, offering new perspectives and interaction possibilities. This immersive capability makes VR a powerful tool, not only for entertainment but also for various fields. VR can be understood as follows:

The meaning of "virtual" is "potential" (from the Latin virtus, meaning strength, energy, power), meaning that a virtual element has the potential to become that element. (…) A digital file is both a real and a virtual object or virtual image [1].

Virtual Reality (VR) is an "advanced user interface" for accessing applications running on a computer. Its characteristics include real-time visualization, movement within three-dimensional environments, and interaction with elements in these spaces. Beyond visualization, the VR user experience can be enriched by stimulating other senses, such as touch and hearing [2].

Virtual reality is a computer-generated digital environment that can be interactively experienced as if honest [3].

Virtual reality (VR) has vast and impactful applications. In education, for example, VR enables the simulation of historical or scientific environments, allowing students to experience simulated or real-life situations for learning purposes. In medicine, the technology is used for training in complex surgeries, increasing the safety and efficiency of procedures.

However, as virtual reality becomes more integrated into our daily lives, discussing issues of inclusion and social sustainability is essential. According to Tori and Hounsell (2018) [1], today's technology enables access to synthetic, immersive, and high-definition environments that can cheaply transport users to alternative realities. Although it can potentially democratize experiences and knowledge, it risks widening inequalities if inaccessible. Digital inclusion must be a priority to ensure that technology benefits a more significant segment of the population rather than

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just a privileged group. Thus, VR implementation initiatives must consider access to tools—whether high-end equipment such as smartphones, headsets, and computers or technologies that users can develop, such as cardboard VR glasses. Ultimately, virtual reality's relevance in the future is intrinsically linked to its ability to promote sustainable and inclusive development

Discussions about the technology must go beyond its immediate applications and incorporate ethical and social considerations. Building a future where virtual reality can be used equitably will depend on collective actions prioritizing inclusion and social responsibility. Only through a critical and committed approach can we ensure that technology serves as a driver of social transformation rather than exclusion.

This research aimed to develop accessible hardware technology for virtual reality in various environments and by a more significant number of people, helping to mitigate the risk of technological advancement becoming a social barrier.

Additionally, an overview of available technologies and VR platforms will be presented. It is important to highlight that this research is an extension of the ICTI e Elas project, which focuses on encouraging girls to complete digital technology courses. As part of this initiative, workshops and experiments with the developed technology were conducted for testing.

Available Technologies

The concept of immersion in Virtual Reality (VR) is linked to creating a haptic illusion for the user through the somesthetic system, which includes human senses within a purposefully designed environment. In other words, the illusion of reality can be perceived through physical devices that "trick" the human nervous system and promote interaction. The environment is designed to emit visual, tactile, and auditory stimuli, which engage the user's sensory receptors. In response, the user reacts emotionally and expresses bodily behavior in a continuous cycle of perception and reaction.

Beyond the virtual environment, which is meticulously developed by designers, engineers, computer scientists, and Human-Computer Interaction (HCI) professionals, physical devices complete the interactive experience. These devices transmit information from the virtual environment to the users, enabling them to "feel" and engage with it. According to Jerald (2015) [3], there are four types of presence illusions in VR:

- Spatial illusion is where the user feels like they are in a specific location.
- Body illusion, where the user perceives themselves as having a virtual body.
- Physical illusion, where the user can interact with elements within the environment.
- Social illusion, where the user can communicate with virtual characters or other users.

Biocca and Levy, cited in Tori and Hounsell [1] highlight that the term Virtual Reality was coined in the late 1980s by Jaron Lanier, an artist and computer scientist who successfully merged two seemingly opposing concepts into a new and dynamic idea—capturing the essence of this technology: the fusion of the real with the virtual. However, the origins of interactive virtual technology date back even earlier. In the 1960s, Ivan Sutherland developed the first VR interaction device—the VR headset (Figure 1), which he named the "Ultimate Display" (Sutherland, 1965) (Packer & Jordan, 2002).

Today, VR hardware consists of various input and output devices that enable immersive interaction with virtual environments. Among the input devices, trackers, electronic gloves, 3D mice, and joysticks stand out, allowing users to communicate intuitively with the system. Displays (Figure 2), in turn, are essential as sensory output elements, covering not only vision but also audio and haptic feedback, which enhances the user experience. The evolution of leading and supporting processors, such as graphics and sound cards, has been crucial in supporting complex three-dimensional applications, reflecting technological advances influenced by the gaming

Figure 1. First VR helmet (produced in the late 1960s). Source: Tori and Hounsell (2018).

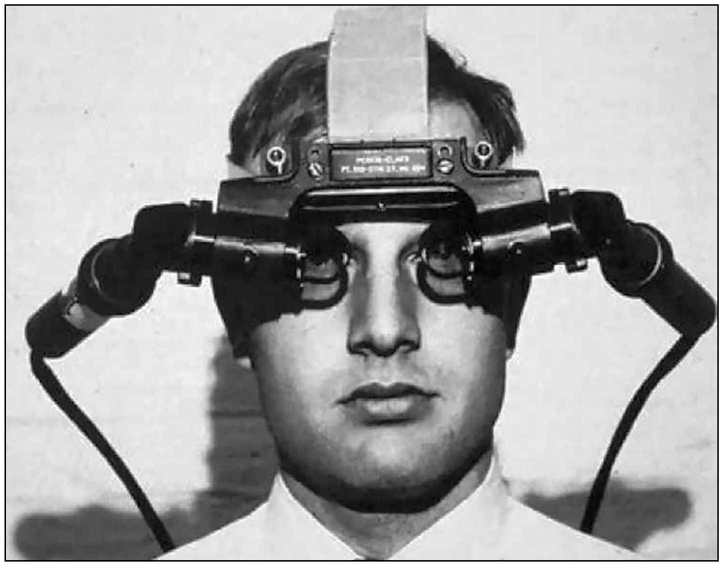


Figure 2. Displays for VR interaction.

market. Among the displays, VR headsets can be mentioned.

In the research, a survey was conducted on the market's most widely used and available VR headset models, as presented in the Table 1.

The virtual environment is typically modeled in 3D modeling software and integrated into platforms that allow user interaction. Platforms for integrating and visualizing the VR environment were researched (Table 2).

Development of Accessible and Sustainable Headsets

Löbach (2001) [4] defines design as realizing an idea into products or models through a constructive process, resulting in a feasible product for mass production. In this regard, it is understood that the product requires techniques that allow for reproducibility—methods that underpin the formal properties, which constitute the configuration, and mainly the technical, operational, ergonomic, and communicative functions [5]. Therefore, the development of a new product, in its complex and interdisciplinary design process, as Mike Baxter states, "*... requires research, careful planning, meticulous control, and, most importantly, systematic methods. Systematic design methods require an interdisciplinary approach, encompassing marketing methods, engineering methods, and applying knowledge in aesthetics and style*" [6].

The principle of the methodological foundations of design and the modeling of its creative journey lies in defining the scope of a problem through both unsystematic and systematic observations [7], with an empathetic focus on understanding the problem and the actors involved. In this problematizing context, the need for the inclusion of all people in the realm of emerging technologies is acknowledged. Considering the advancement of VR worldwide, designing a cheap and efficient product for future professionals becomes essential to technological progress.

The second phase involves data collection and analysis of similar products. Google's cardboard (Figure 3) was tested as a reference for low-cost headsets, as presented in Table 1. However, the proposed model became problematic due to the complexity of its layout, requiring specific cuts that are difficult to reproduce manually in series. The cardboard consists of three separate structures that are cut out individually and then assembled.

Preliminary formal studies were conducted using cardboard with the conceptual proposal of reducing cut areas, simplifying the cuts, minimizing glue points, and incorporating interlocking points to ensure proper assembly. In this regard, the layout shown in Figure 4 was developed. The proposed headset consists of 4 pieces, which, after being cut, are assembled according to the indicated letter markers and glued together using hot glue.

The production of sustainable lenses was also investigated. Given the complexity of producing lenses from PET bottles and water, which is commonly suggested on maker websites, the manual production of sustainable lenses proved imprecise, hindering the final visualization of the VR environment. Therefore, considering the cost of acquiring 25mm biconvex lenses without flanges, it was decided to purchase them for R$19.50 per pair of glasses.

In the prototyping phase, the glasses were assembled and tested with users – girls from the Colégio Estadual Polivalente de Camaçari (Figure 5). The most significant difficulty they encountered was adjusting the distance between the screen and their eyes and ensuring the smartphone's stability during use so that when they moved their heads, the smartphone remained fixed within the headset. The test was conducted with users who experienced the homemade cardboard headset and the Quest 2. After adjustments, the user experience with the developed cardboard headset showed satisfactory results compared to the Quest 2.

Development of Accessible and Sustainable Headsets

The research concludes that the goal was achieved through the development of a paper

Table 1. Description and cost of VR headsets.

Headset	Description	Cost
Quest 2	The Oculus Quest is a standalone VR headset developed by Facebook. It features a high-resolution display of 1832x1920 pixels per eye, a 90Hz refresh rate, and a Snapdragon XR2 processor. The motion controllers provide precise tracking, and the device is available in storage variants.	R$ 3,480.00
Quest 3	The Meta Quest 3 is a standalone VR and augmented reality headset developed by Meta. Equipped with a Snapdragon XR2 Gen 2 processor, 8 GB of RAM, and available in 128 GB and 512 GB storage versions, it offers an immersive experience without the need for a computer or console connection. It includes RGB cameras for external world view, infrared sensors for gesture reading, and depth adjustment.	R$ 4,089.90
HoloLens 2	The HoloLens 2 is an augmented reality (AR) headset developed by Microsoft. Released in 2019, it offers an advanced AR experience with a 2K display. Powered by a Qualcomm Snapdragon 850 processor, it includes eye and gesture tracking for natural interactions. Its field of view is wider than its predecessor, designed for prolonged use with a lighter, more comfortable frame. It is mainly intended for business applications such as training, design, and remote collaboration.	R$ 35,800.00
Valve Index	The Valve Index is a VR headset developed by Valve Corporation and launched in 2019. It features an LCD with a refresh rate of up to 144Hz, providing an immersive visual experience. The field of view is about 130 degrees, offering a wide and engaging view. Motion controllers provide precise tracking and a variety of interactions while the audio system is integrated.	R$ 10,498.00
PlayStation VR	The PlayStation VR is a VR headset developed by Sony. Released in 2016 for PlayStation 4, it offers a VR experience with a 1920x1080 pixel OLED display and a refresh rate of up to 120Hz, delivering sharp graphics and an engaging visual experience. It uses PlayStation Move motion tracking technology and the PlayStation Camera to detect player movements.	R$ 4,599.90
HTC Vive Pro 2	The HTC Vive Pro 2 is a VR headset developed by HTC. It features a 5K display (2448 x 2448 pixels per eye) with a refresh rate of up to 120Hz. The field of view is about 120 degrees. It is compatible with SteamVR motion tracking and is primarily designed for gaming, simulation, design, training, and entertainment applications.	R$ 12,899.00
HTC Vive Cosmos	The HTC Vive Cosmos is a VR headset released by HTC. It has a screen resolution of 2880 x 1700 pixels combined (or 1440 x 1700 pixels per eye) and a refresh rate of 90Hz. The field of view is about 110 degrees. The Vive Cosmos uses inside-out tracking, meaning the sensors are embedded in the headset, eliminating the need for external sensors.	R$ 9,689.00
Vive Cosmos Elite	The HTC Vive Cosmos Elite is a VR headset designed by HTC. It offers a screen resolution of 2880 x 1700 pixels combined (or 1440 x 1700 pixels per eye) and a refresh rate of 90Hz. The field of view is about 110 degrees. The Cosmos Elite uses external sensor-based tracking, providing enhanced precision and a more robust tracking experience, which is ideal for intensive gaming and simulations.	R$ 9,698.00
Google Cardboard 3D VR Glasses	Developed by Google for use with smartphones, Google Cardboard is made of cardboard and has a simple design. It is compatible with most smartphones up to 6 inches in size, provided the device has an embedded gyroscope (present in most newer smartphones). Users can use specific apps to watch 360° videos, play VR games, take virtual tours, and participate in various interactive experiences.	R$ 14.90

Table 2. VR Environment integration and visualization platform.

Platform	Link	System	Description
Resonite	resonite.com	PC Steam	A social VR platform (also available in desktop mode) where users can create interactive objects, avatars, and maps using a visual programming system.
Frame	learn.framevr.io	Web	This platform is a web-based platform that allows users to create their own 3D virtual spaces and avatars to interact with others in a metaverse environment. It can be accessed from a computer, tablet, smartphone, or VR headset.
Spatial	spatial.io	Web	It is a web-based platform that allows users to create their own 3D virtual spaces and avatars to interact with others in a metaverse environment. It is accessible from a computer, tablet, smartphone, or VR headset.
Third Room	thirdroom.io	Web	It is a web-based platform where users can create their own 3D virtual spaces and avatars to interact with others in a metaverse environment. It can be accessed from a computer, tablet, smartphone, or VR headset.
Overte	overte.org	PC	An open-source social VR platform (also available in desktop mode) where users can create interactive objects, avatars, and maps using JavaScript programming.
Aframe js	aframe.io	Web	A JavaScript framework for creating 3D experiences on the web, with the ability to access in VR.
Godot Engine	godotengine.org	PC + Quest/ Pico	An open-source game engine that can be used to create VR games.
Unity	unity.com	PC	A platform for creating 3D and 360-degree games, models, and VR experiences.

VR headset with biconvex lenses and the use of smartphones for environment transmission. This represents accessible hardware technology for VR use, potentially reaching a larger and more diverse audience. However, it is still necessary to understand the challenges and the potential for innovation and creativity in the product. One of the main challenges is related to the durability and robustness of the material used. Although cardboard is an accessible and sustainable solution, it is susceptible to wear, especially when exposed to prolonged use or environments with high humidity. Additionally, the ergonomics of the headset is another limiting factor. Due to its rigid material and lack of precise adjustments, user comfort is often compromised, particularly during longer immersion sessions. From a technical perspective, one of the challenges is the imprecision in the distance between the lenses and the smartphone screen, which can affect the quality of the visual experience and cause eye strain.

Figure 3. Google cardboard mockup.

Figure 4. Layout of the developed headset.

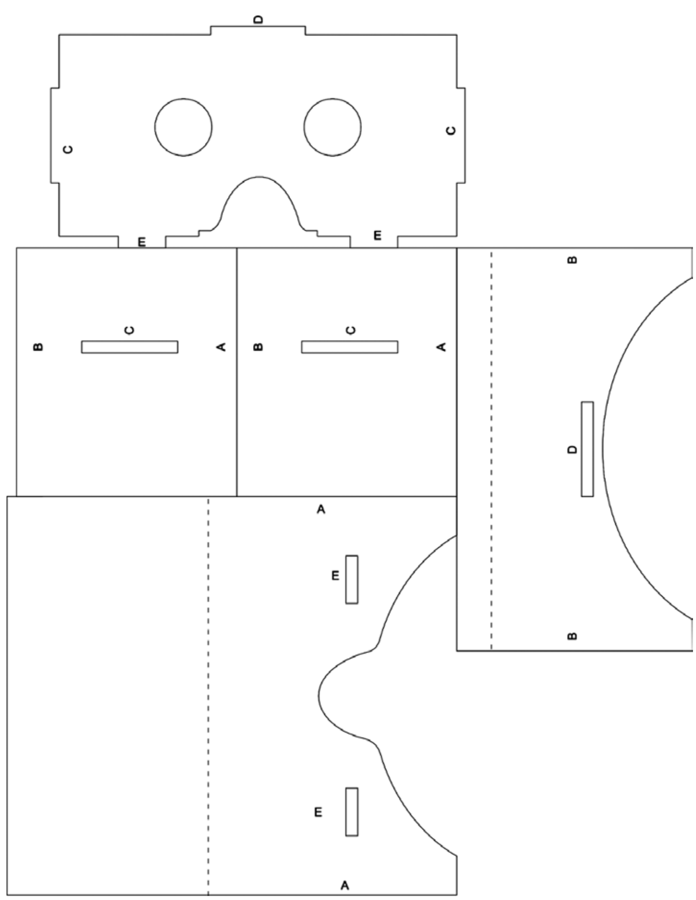
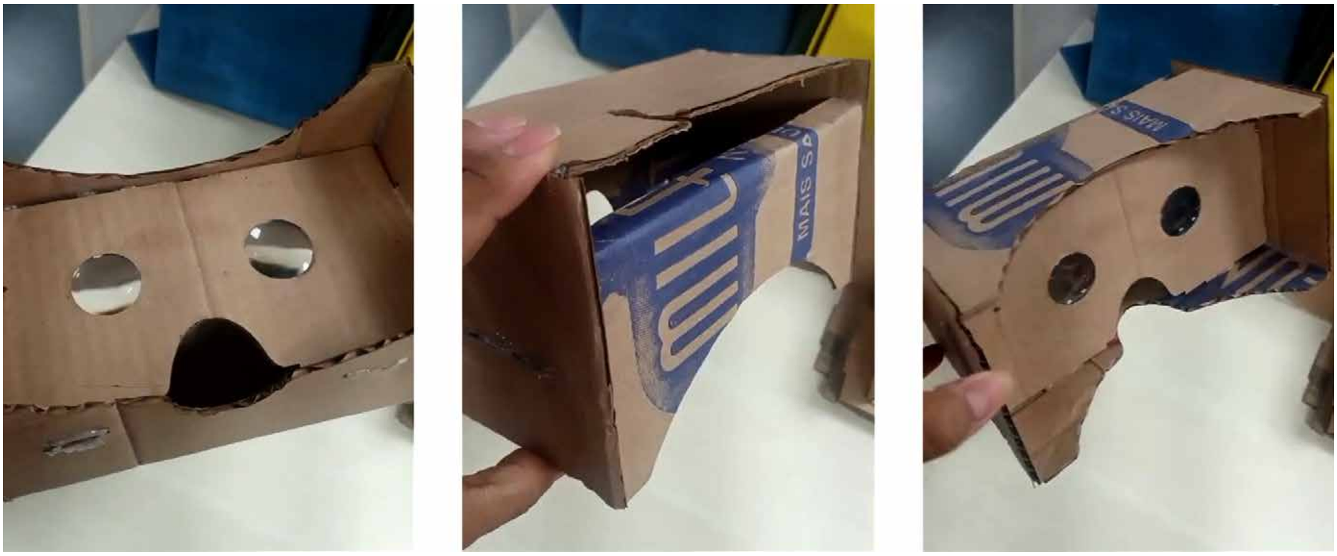


Figure 5. Prototype of the developed and tested headset.



Several solutions and improvements can be implemented, such as using more durable materials like treated cardboard or more resilient recyclable composites, increasing the device's lifespan without compromising its low cost. Adjustable supports or padding in areas that contact the face could make the headset more ergonomic for a broader range of users. Regarding the technical aspect, developing a smartphone fixation system that ensures stability during use, even with more intense head movements, is crucial.

In the field of design, despite its structural simplicity, the device allows designers to explore new ways to develop accessible and sustainable products. The fact that the cardboard headset can be assembled manually or on a small scale opens up opportunities for customization and adaptation, serving various audiences from students, researchers, and professionals in the field. This promotes accessibility and democratization of VR access in a scenario where cutting-edge technology is financially unfeasible for many people. This means more individuals, schools, and communities can access VR, using it as a learning, experimentation, and innovation tool.

The developed prototype was delivered to the Colégio Estadual Polivalente de Camaçari, becoming an example of how this technology can be practically applied in the educational context. It serves as an immersive experience and a means to encourage creativity and innovation in the learning process. Students could create content and adapt the headset for different needs, fostering a continuously innovative environment.

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