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Additive manufacturing in the development of low-cost immersive virtual reality solutions for education: a study with google cardboard

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Abstract

Virtual Reality (VR) is a technology that makes it possible to create simulated worlds using computer systems. This study presents a proposal to develop a Google Cardboard prototype using additive manufacturing. The central aim of the study is to contribute to the understanding of low-cost Immersive Virtual Reality (IVR) alternatives; to assist in the scientific-technological development of IVR solutions; and to contribute to technological development and access in a social context and to the preservation of the environment through sustainable technological solutions. Developed in two stages, the theoretical foundation aimed to systematize and understand the concepts involving VR, low-cost solutions for VR - specifically Google Cardboard - and additive manufacturing. The experimental research involved producing the Google Cardboard from the specifications provided by the company, creating a digital model of the display, printing the 3D model and testing the prototype developed. The results of the study indicate that additive manufacturing could be a promising technology for developing low-cost and sustainable VR solutions. The use of filaments made from recyclable materials, such as PET, can help reduce the environmental impact of this type of technology, as well as providing the possibility of social transformation. Therefore, this study contributes to advances in the development of accessible and sustainable solutions in VR, cost reduction, the evolution of Google Cardboard and understanding of the concepts involved. Limitations include the lack of tests with real users and the failure to investigate the impact of focal distance on visual comfort.

Keywords: 3D Printing, Fused Deposition Modelling, Learning, Smartphone, 3DOF and 6DOF

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1. Introduction

Immersive Virtual Reality (IVR) is a computer technology that creates and maintains a simulated environment in which users can insert themselves and interact, providing a sense of physical presence (Cipresso et al., 2018).

Although it emerged in the 1960s, VR has become increasingly prominent due to the continuous development of applications and software that improve user experience and interaction. In addition, the improvement of VR devices, such as immersive glasses and 360° cameras, has boosted its applicability in various sectors, such as education, engineering, military training, health, and others (Matthews, 2018; Cipresso et al., 2018).

The use of VR in education has shown significant potential to transform the way students learn. For example, VR can create simulated environments that allow students to explore complex concepts in a practical and immersive way. They can carry out scientific experiments, visit historical sites, interact with 3D models, and simulate real-world situations that would be inaccessible or dangerous in a traditional classroom environment (Souza Filho and Tritany, 2022).

The application of VR in education also has the potential to increase student engagement, making lessons more interactive and stimulating. Students can become active protagonists in their learning process, exploring and experimenting with concepts in a practical way, which can facilitate understanding and knowledge retention.

Despite proving to be beneficial, the development of VR can still be challenged by its cost (Matthews, 2018). To mitigate this problem and promote the development of the sector, solutions such as Google Cardboard have been proposed. Google Cardboard is a low-cost, open-source VR display and SDK made of cardboard that uses the smartphone as a screen (Google B, 2023).

To analyze and maximize the use of VR, the main objective of this study is to develop a low-cost solution based on the Google Cardboard proposal through additive manufacturing, validating the possibility of using filament produced from recyclable material. The specific objectives were: to contribute to the understanding of low-cost VR alternatives; to assist in the scientific-technological development of VR solutions; and to promote technological access in a social context and with the preservation of the environment through sustainable technological solutions.

1.1. Immersive Virtual Reality (iVR) concepts and applications

Virtual Reality (VR) as a technology that has been researched and developed since the 1960s, has only really become popular in recent years. VR is a technology that, as established by (Hale & Stanney, 2014), seeks to provide the user with the possibility of interacting with a 3D computer model through a screen, thus giving the user a sense of immersion in these environments and even making it possible to manipulate it (Earnshaw et al., 1993), establishes that VR is a multisensorial experience, which through the tracking of head and body movements can offer a sense of immersion.

According to these definitions, it is possible (Cipresso et al., 2018) to establish levels of immersion offered by VR technology. These levels are organized according to levels of immersion, interaction, and perception of the environment. VR can therefore be non-immersive, immersive, and semi-immersive.

The non-immersive VR is basically an offer of interaction through screens that can reproduce images of the simulated domain. Although it enables visualizations of simulations, this type of VR provides the user with a two-dimensional (2D) perspective of the environment (Cipresso et al., 2018).

Different from previous VR systems, Immersive Virtual Reality (iVR) can offer a complete sensorial immersion experience for the user through devices with screens mounted on the user's head. These devices can track the movement of the user's head, altering their perspective within the simulated environment (Assumpção & Cuperschmid, 2021).

Semi-immersive environments, on the other hand, allow a change in the perspective of the simulated environment by offering a representation in three dimensions (3D), which can be visualized through a screen where it is possible to change the perspective of the environment using a pointing device (Cipresso et al., 2018).

In addition to the characteristics presented previously, VR can also be categorized as 3DOF and 6DOF. The term DOF stands for Degree Of Freedom and refers to the forms of freedom that the device can provide the user, concerning the position and orientation of the camera within three-dimensional space as shown in Figure 1 (Assumpção & Cuperschmid, 2021).

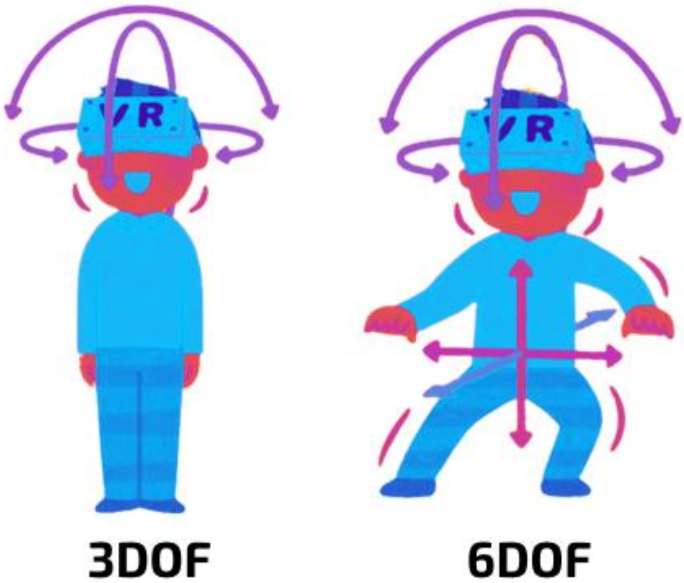


Figure 1: Adaptation from (Assumpção & Cuperschmid, 2021) the figure shows 3DOF where it is possible to check that only head movement is tracked, and 6DOF where body movement is also taken into account for positioning within the 3D environment.

Source: Adaptation from Assumpção & Cuperschmid, 2021

As can be seen in Figure 1, 3DOF can track the orientation of the user's head in all directions, while 6DOF offers more freedom by evaluating and tracking other parts of the body.

All of these forms of VR are interesting for learning processes, however, this work endeavors to focus on 3DOF VR, through its low-cost solution for this sector.

1.2. Google Cardboard RVi for all

Imagine having access to VR content with just your smartphone and a few pieces of cardboard - that's what Google Cardboard is all about. Google Cardboard is a virtual reality (VR) platform developed by Google. It's a low-cost device that allows users to experience virtual reality using a smartphone. Google Cardboard is made of cardboard and has two lenses, which project the image of the smartphone in front of the user's eyes (Google A, 2023, Cipresso et al., 2018, Cheong et al., 2023). Figure 2 shows the Google Cardboard once it is ready.

Figure 2: Google Cardboard ready for use.

Source: Google A, 2023

In November 2019, Google made the software development kit (SDK) for the Cardboard platform open source, allowing anyone to create their own VR experiences (Cheong et al., 2023). As well as opening up its code, the company is encouraging other manufacturers to create their versions of the device. Based on this possibility, this work attempted to create a version of this display using additive manufacturing to create a sustainable version based on filament produced from recyclable material, specifically PET used in soft drink bottles.

1.3. Prototyping using additive manufacturing

Prototyping using additive manufacturing is a rapidly evolving technology that is becoming increasingly important in the development of new products and the production of end-use parts. As defined in (Oliveira et al., 2018) prototyping using additive manufacturing is a process of creating a prototype of a three-dimensional object, layer by layer, from a digital file. According to the authors, as defined by ASTM International, it is possible to create, using an additive manufacturing machine, a three-dimensional object, layer by layer, from a digital model with a variety of materials such as polymers, metals, ceramics, and composites. This demonstrates the possibility of building the display proposed by (Google B, 2023).

The prototyping process is relatively simple, and there are several technologies available on the market for producing parts manufactured through material extrusion. Among these are the low-cost technologies that have emerged recently. These technologies are based on the principle of material extrusion, specifically FDM (Fused Deposition Modelling) technology, which is the technology used in this study (Oliveira et al., 2018).

An FDM machine builds a prototype by depositing extruded material. The extrusion head, which moves in the X and Y axes, positioned on a table that moves in the Z axis, continuously receives the material in the form of a thread. The material is heated to the semi-liquid or pasty point and then deposited in the appropriate place to form a layer of the desired geometry. The table then moves along the Z-axis and the process is repeated until the prototype is complete.

2. Material e Methodology

The methodology adopted in this study followed the following steps: (a) theoretical foundation to understand the concepts involving VR, low-cost solutions for VR, specifically Google Cardboard, and additive manufacturing. In addition to understanding the concepts involved, this stage also served to establish the characteristics to be assessed, defining: mounting structure, weather resistance and durability, ease of assembly, and whether the type of visualization of the immersive 3D environment. Another aspect raised at this stage was the possibility of building the prototype display from recyclable material. (b) Experimental research, which involved the following activities: i) Production of the Google Cardboard from the specifications provided by (Google C, 2023); ii) creation of a digital model representing the Google Cardboard; iii) printing of the 3d model created using an FDM printer; iv) and testing of the prototype developed and its suitability for the Google Cardboard proposal.

2.1. Production of Google Cardboard

The production of Google Cardboard is based on the specifications provided by the company for the production of the display (Google C, 2023). Figure 3 gives an overview of the elements needed to produce the display.

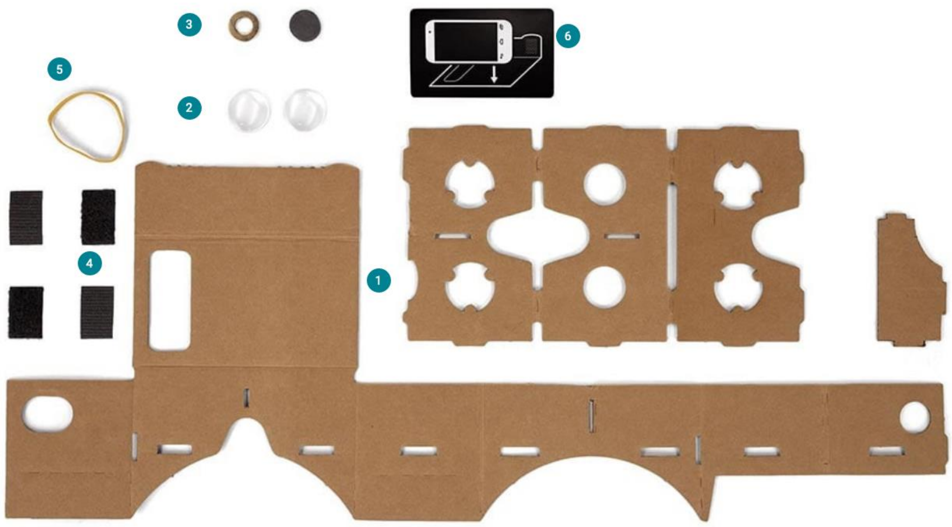
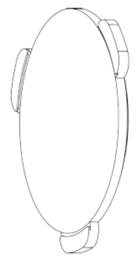


Figure 3: Overview of the materials needed to produce Google Cardboard. 1-Chassis and shirt; 2-Lenses; 3-Button (neodymium magnet); 4-Velcro; 5-Elastics responsible for closing the glasses; 6-layout with the smartphone position.

Source: Google A, 2023

The construction of this display required biconcave lenses that allow users to focus their vision on the smartphone screen and allow the smartphone to be positioned at short focal lengths (2-5 cm). This element is perhaps the most expensive in the entire production of the display. Figure 4 shows the characteristics of the reference lenses presented in the documentation (Google C, 2023).



Parâmetros	Valor	Unidade
Campo de visão projetado	80	°
Diâmetro da pupila	15	milímetros
Alívio de olho	18	milímetros
Distância nominal da imagem virtual	-667	milímetros
Diâmetro da lente	34	milímetros
Material da lente	PMMA	

Figure 4: Lens reference for use in Google Cardboard.

Source: Google C, 2023

In addition to the lenses, as seen in figure 3, a template is needed to cut out the cardboard in order to build the structure of the display body, which is made up of three parts: the chassis, the jacket and the button (neodymium magnet), all of which are made from corrugated cardboard. Figure 5 shows the final construction of the chassis with its respective parts assembled.

Figure 5: Google Cardboard display assembled for the experiment, according to the specifications in (Google C, 2023), and shown in figure 3.

2.2. Creation of a digital model to represent Google Cardboard.

The process of creating a digital model to represent the Google Cardboard with the necessary corrections for problems initially observed in the Google Cardboard model. For this process was used FreeCAD, an open-source parametric 3D modeller created primarily to design real-world objects of any size. This type of modelling makes it easy to modify the project by going back in history and changing parameters. Figure 6 shows the chassis developed as a digital model and its FDM-printed counterpart.

Figure 6: Digital model of the prototype and its FDM printed equivalent. 1: Lens holder; 2: Smartphone holder; 3: Lens base; 4: Lens adapter; 5: Button; and 6: Body.

2.3. FDM printing of the prototype

In the process of printing the digitally created 3D model, FDM printers were used, specifically in this study the 3DMax G4 printers and the Criality Ender 3 v2 printer. After creating the digital models described in activity ii) they were then sliced to be printed by the printers mentioned. The slicing process is the construction of the lines of code needed to make the printer understand how the printing process should be carried out. The slicing programme called Ultimaker Cura was used for this task. This is also open source software developed for slicing 3D objects and is highly parameterisable for different materials and 3D printers.

Figure 7 shows the items described in figure 6, presented earlier printed in FDM and already assembled in the prototype.

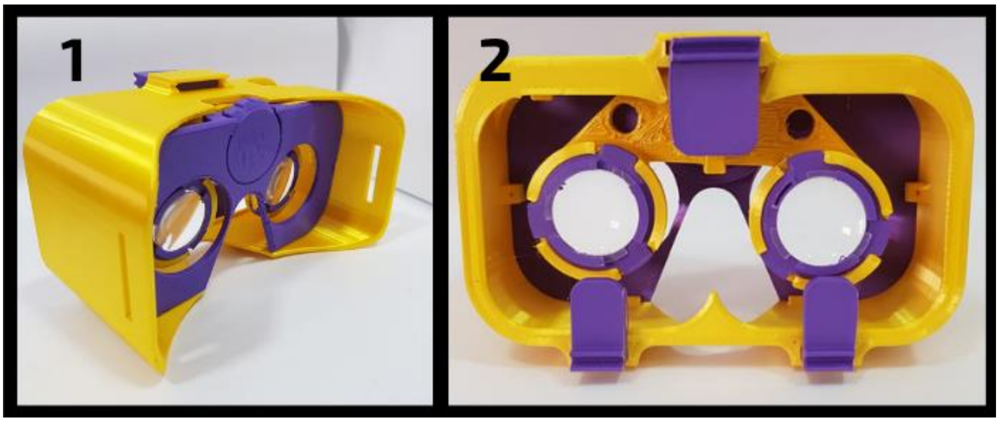


Figure 7: Prototype assembled after FDM printing. 1: rear view; 2: front view.

2.4. Testing the prototype and adjusting it to Google Cardboard

The process of testing the prototype developed and its compatibility with the Google Cardboard proposal was carried out taking into account the mounting structure, weather resistance and durability, ease of assembly and whether the type of visualisation of the immersive 3D environment was the same on both devices. In this regard, the application offered by Google in its SDK was used as a reference. For the assembly structure test, the possibility of different devices was assessed, or even for a given device to adapt to the visual needs of different users. In terms of resistance and durability, the test was based on resistance to exposure to water. The assembly process was tested, taking into account whether the display could be assembled without the need for specialised tools. Finally, the visualisations generated by both devices were evaluated to see whether or not they were similar.

3. Results and Discussions

This study aimed to potentialise the use of VR by developing a low-cost solution based on the Google Cardboard proposal through additive manufacturing. The purpose is to validate the possibility of using a filament made from recyclable material, making the solution not only sustainable but also a form of social change. The results obtained in the experimental research showed that it is possible to produce a Google Cardboard prototype using additive manufacturing.

However, during the process of replicating Google Cardboard from the documentation available (Google, 2023), the following structural problems were observed in the construction of the display: lack of the possibility of using different smartphone devices using the same display, lack of adjustment of the distance between the lens and the smartphone and lack of adjustment of the focal length which corresponds to the distance between one iris and the other. Although it is a low-cost and relatively sustainable viewfinder, Google Cardboard also proved to be fragile when used for long periods, with problems with exposure to elements such as water or sweat and the impossibility of sanitizing it between uses, as seen in Figure 5 - the display is made of paper. Another important feature when using the display was that in this version it is only adapted to the 3DOF VR model.

The digital model developed was able to correct some of the problems observed in the Google Cardboard model, resulting in a prototype with better build quality. Figure 8 shows the device adapter, the interchangeable part responsible for allowing different smartphone models to be used in the same device.

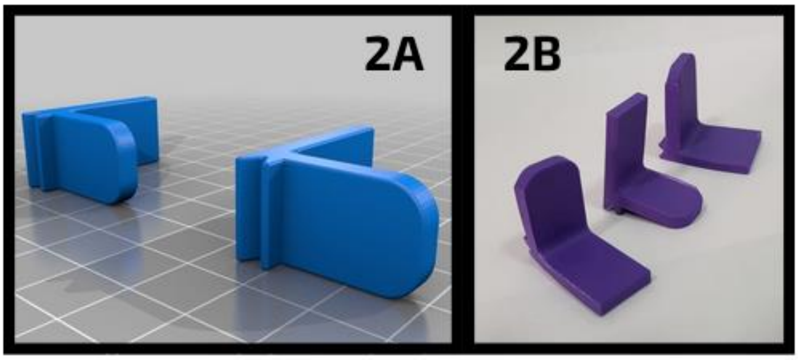


Figure 8: Adapter for Smartphone devices. 2A: digital model; 2B: FDM printed model.

Another problem solved in the digital model is adjusting the distance between the lenses and the smartphone. This adjustment is made using a screw-like part which, when rotated, moves the lenses closer and further away from the smartphone and consequently does the same process for the viewer's eyes. Figure 9 shows this part. In this model, it has not yet been possible to correct the focal length mentioned above as one of the problems raised in Google Cardboard.

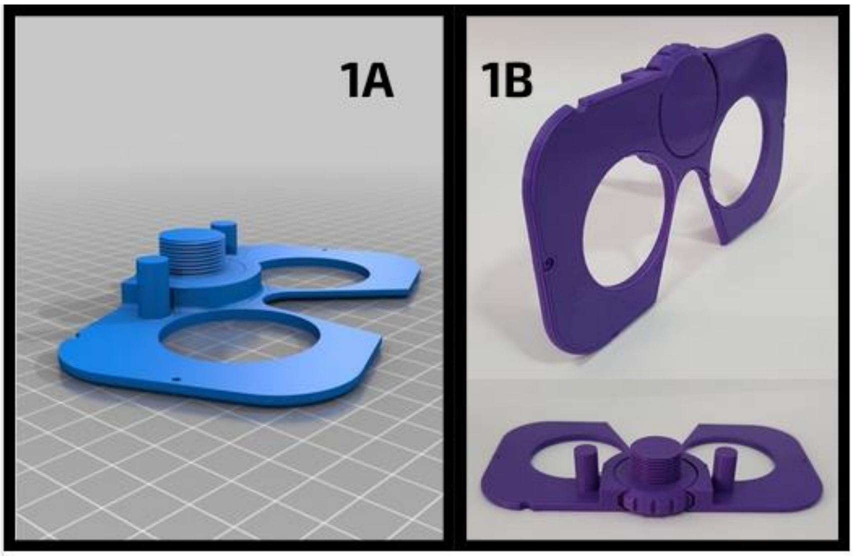


Figure 8: Mechanism for moving the lenses closer and further away from the smartphone device and the user's eyes. 1A: digital model; 1B: FDM printed model.

The characteristics related to the fragility in handling, exposure to elements such as water and sweat, and the possibility of sanitisation have been resolved through the use of filaments made from plastic polymers. This means that the display is no longer sustainable, a problem that can be solved by using filament made from recyclable material. Figure 10 shows the two displays built in this study.

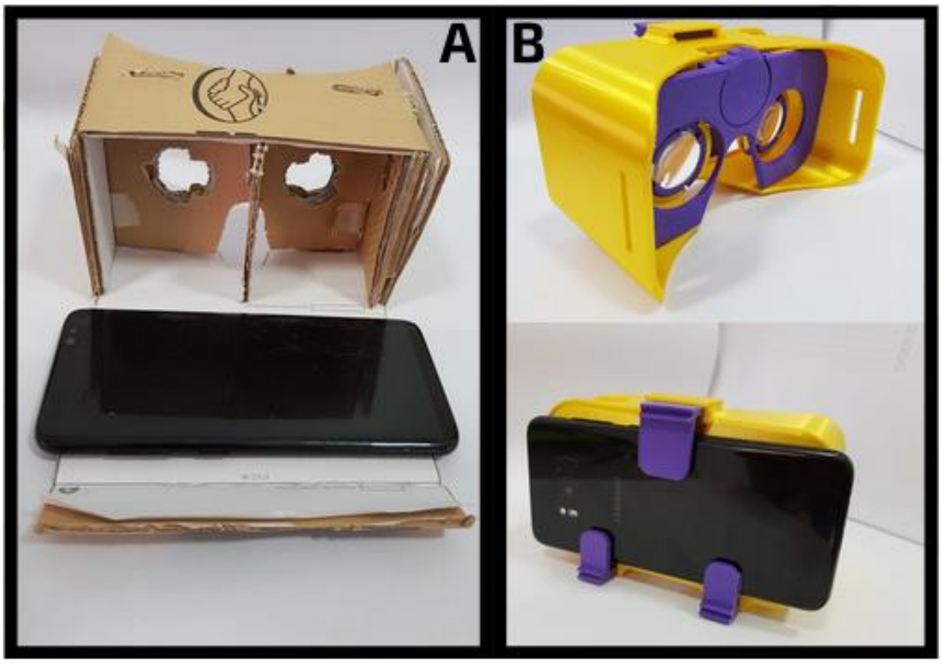


Figure 10: Displays produced during the study side by side. A: cardboard model; B: FDM printed model.

The 3D model printing process was carried out with a high percentage of success, using two different FDM printers. Most of the problems encountered in this process were due to power outages, which on the Ender 3 printer were solved by restarting the printing functionality of the printer itself, however on the 3Dmax, which does not have this feature, the prints had to be restarted from the starting point.

The prototype test showed that it is possible to obtain similar images on both versions of the device, both the model produced from cardboard and the printed prototype.

The whole process has produced promising results in terms of democratizing access to VR technology. By producing a display model that lasts longer, it is possible to think of public policies that could exploit this display in public educational institutions. Furthermore, with the indication that it is possible to print this display using recyclable materials, based on the idea that all that is needed is to change the type of filament used in FDM printers, a new door is being opened to aspects related to sustainability and social change.

By using recyclable material in the production of the display, it is possible to reduce the impact of plastic polymers on the environment by recycling these materials. In this process, production chains can be generated involving those people who obtain their main income from collecting recyclable materials.

4. Conclusions

The application of iVR in education promotes a new way of engaging and stimulating students. The main aim of this study was to develop a low-cost prototype for Immersive Virtual Reality (IVR) based on the Google Cardboard proposal, using additive manufacturing. From the results obtained during the construction of this study, it was possible to conclude that the prototype is a viable and interesting solution for democratizing the use of iVR.

Some challenges remain even after this study, such as the focal length and the question of sustainability. For both challenges, it is already possible to visualize a solution by improving the design of the prototype and using a filament made from recycled material.

The development of a low-cost prototype iVR display with the potential to be made from recycled materials is a significant step towards democratizing technology and building a more sustainable and socially just future by enabling its application in education.

This study demonstrates the potential of combining iVR with additive manufacturing to develop low-cost iVR solutions with greater social impact. The research paves the way for future investigations that seek to improve the prototype and expand its use in different areas such as: investigating solutions for correcting the focal distance in the prototype; developing and testing prototypes using recycled filaments from different materials; assessing the feasibility of implementing the prototype in educational and social environments; and analyzing the social and environmental impact of producing iVR display with recycled materials.

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