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5 SCIENTIFIC PROBLEMS FOR IMMERSIVE INTERACTIONS DESIGN WITHIN VIRTUAL REALITY APPLICATIONS DEVELOPMENT PIPELINE

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ABSTRACT

Virtual reality (VR) has emerged as a transformative technology with multifaceted applications across gaming, education, and industry. It is also align with Sustainable Development Goal (SDG) in Industry, Innovation, and Infrastructure, by fostering innovation and technological advancement. However, the inherent complexity of VR application development presents challenges, particularly in immersive interaction design within the development pipeline. In this review, we emphasize the importance of addressing five scientific problems pertaining to interaction design within the VR application development pipeline. By shedding light on these challenges, we aim to stimulate discussion, propose solutions, and ultimately contribute to the advancement of VR techniques and applications, with a particular focus on immersive interaction design. We endeavor to support the realization of SDGs by harnessing VR technology to drive innovation, enhance accessibility, and promote sustainable development across various sectors.

Keywords: *virtual reality, state of the art, immersive interactions design*

1. INTRODUCTION

Virtual reality (VR) technology holds immense potential to advance multiple Sustainable Development Goals (SDGs). With VR's ability to create immersive environments and enhances accessibility, this convergence opens possibilities across various domains including training, entertainment and education. In the education sector, VR presents a revolutionary tool for delivering content [1]. VR transcends physical barriers, such as traditional learning are disrupted, such as during crises like pandemics or endemic outbreaks, VR-enabled systems promote inclusive and its align with SDG 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure).

Beyond education, VR technology can contribute significant revenue to the metaverse and gaming industries. According to reports from Bloomberg and various research firms such as NewZoo, IDC, PWC, Statista, and Two Circles, the global potential revenue from the Metaverse is projected to increase to $800 billion in 2024, up from roughly $500 billion in 2020 [2]. By 2024, developers of online games and gaming hardware are expected to dominate the market with an estimated $400 billion. Researchers envision the future of the metaverse to encompass a wide range of content designed to capture and sustain the attention of individuals within VR [3-5]. Customizable digital avatars and environments are currently at the forefront of metaverse development. Commercially available platforms such as Roblox [6] and Sandbox [7] provide users with game development environments, enabling them to create their own games and participate in those created by others. For example, Sandbox facilitates game creation without requiring programming skills, relying on a drag-and-drop approach. Although, this platform is capable of making an interesting entertainment experience, it is difficult to design immersive interactions, e.g., an interactive experience to explain the intricacies of sonic wave behaviour based on specific variables in of wavefields.

There are a few of VR industry-standard game engines like Unity (https://unity.com) and Unreal Engine (https://www.unrealengine.com) that are offering rich immersive interaction design, but the available VR-specific support in these engines remains relatively limited. Notably, using these tools can be programming-intensive, time-consuming especially for immersive interaction design [8-10]. Additionally, there is numerous commercially available software built on top of those engines, of those engines, e.g., Sim Lab [11], they often have limited immersive features and lack of clear and readily available standard workflows specifically for immersive interaction design. Designing immersive interaction experiences presents a challenging and complex task for VR applications [9, 12, 13]. The challenge lies in striking a delicate balance between visual appeal and technical complexities to deliver an immersive and realistic VR environment [14]. The complexity of the immersive interaction design is a crucial factor in developing high-quality VR applications [15]. The immersive design might be varies depends on the requirement of the output, certain works might require tactile feedback instead of fully computer simulation. Given the multitude of challenges in VR application development, it is crucial to explore each stage of the process in detail. By doing so, developers can understand the problems that affect the quality of VR experiences. The VR development pipeline typically involves various stages. At each stage, careful consideration must be given to enhance the interaction mechanisms. These factors give main contributions to the overall sense of presence.

The structure of the paper is as follows: First, we describe the method for the review. Second, we derive the generic VR application development pipeline based on the review analysis. Third, we highlight and discuss the issues related to immersive interaction design at each phase of the pipeline. Finally, we conclude our findings by discussing the implications and opportunities for future research in VR immersive interaction design.

2. METHOD

For the literature review, we adopt the PRISMA method [16]. Firstly, we locate existing studies in mainstream online academic databases: ACM Digital Library, IEEE Xplore, Science Direct and Scopus. The search criteria includes strings with term of "virtual reality", "virtual reality development", "process" and "workflow", and "pipeline". Then we select the suitable article, i.e., works associated with complex knowledge domains. Then, we analyse their contributions and then we synthesis and evaluate the data. In total 317 related articles were selected (refer to Table 1).

Table 1: Review sources: Search databases and number of results

Database	Results
ACM Digital Library	83
IEEE Xplore	88
Science Direct	126
Scopus	20
Total	317

3. VIRTUAL REALITY APPLICATION DEVELOPMENT PIPELINE

To study the problems for immersive interactions design particularly within virtual reality applications development pipeline, we first study the general pipeline for VR development. Table 2 shows the key stages that have been identified for the VR development process from the literature. Then, we simplify the generic VR application development key stages into a generic pipeline as in Figure 1. It resembles the overall VR application development with immersive interaction design.

3.1 VR Project Initiated

The initial and pivotal step in creating a virtual world involves generating a high-concept idea. The typical workflow for developing VR applications is set into motion when there's a request to incorporate VR technology in a project [17, 18]. The process commenced with a concept creation workshop during the early phase, where the project was initiated with the formulation of a conceptual idea. This was followed by phases of early sketching and progressing towards prototyping [19]. In this phase the immersive interaction design is discussed and planned.

3.2 Creating 3D scene

This stage allows users to assemble and disassemble objects as needed, utilizing the original design structure extracted from the 3D mesh file. In here, 3D objects retrieval method usually used to prepare the VR environment.

3.3 VR Interaction Development

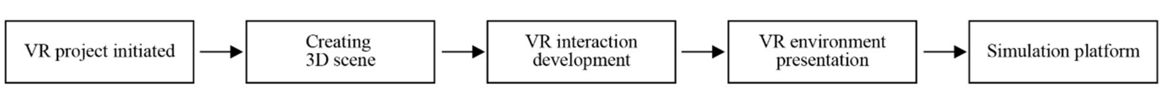

Figure 1: Generic VR application development pipeline

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The interaction between the user and the virtual environment is known as natural interaction. This type of interaction aims to provide users with a similar experience to the real world through feedback mechanisms. Procedural or practical knowledge-oriented VR applications mainly applied the fundamental interaction element. There is no standard set of guidelines regarding the design elements considered appropriate for specific VR applications. For example, users can interact with virtual objects in a variety of ways, such as retrieving additional information about an object in text or audio form, grabbing and rotating the object, zooming in to see more details, and changing the color or shape of the object. The interaction input includes various human motions and interaction inputs, e.g. gaze-based interaction, controller-based point interaction, compound interaction [20].

3.4 Virtual Environment Presentation

Building a full virtual environment requires stimulating all the senses, and VR currently best simulates the visual and auditory experience. The interaction design in virtual environment is related to other concepts such as embodiment [21], place [22] and plausibility illusions [23].

3.5 Simulation Platform

There are three main types of VR applications: non-immersive, semi-immersive, and fully immersive. Non-immersive VR lets you interact with virtual environments on a regular screen, like examining a 3D product with your mouse. Semi-immersive VR offers a step up from flat-screen experiences, e.g., exploring 360° videos with a smartphone sensors or gamepad control. Fully immersive VR creates realistic virtual worlds where you can move freely and interact with objects using hand controllers and tracked movements. VR enables users to participate in realistic simulations or virtual explorations that would be otherwise impractical or too hazardous to carry out in the real world. The best VR applications begin with choosing a suitable platform and software development kit (SDK) [14].

4. 5 SCIENTIFIC PROBLEMS RELATED TO IMMERSIVE INTERACTION DESIGN IN VR APPLICATION DEVELOPMENT PIPELINE

We found a few challenges in each stage of the VR application development pipeline (Figure 1). These challenges were synthesized as 5 scientific problems related to immersive interaction design (Table 3).

Table 3: Summary of 5 scientific problems

5 Scientific Problems for Immersive Interaction Design in VR Development
1. Lack of sophisticated authoring tools: problems related to develop content for VR environments
2. Challenge in creating realism and its input: problems related achieving a high level of realism
3. The intuitive interaction in VR is crucial: problems related intuitive and seamless for users to fully engage with virtual world
4. VR hardware compatibility: problems related to reliable across different hardware platform
5. The occurrence of simulation sickness: common issue experienced by some users

Figure 2 illustrates the problems within the pipeline based on previous research.

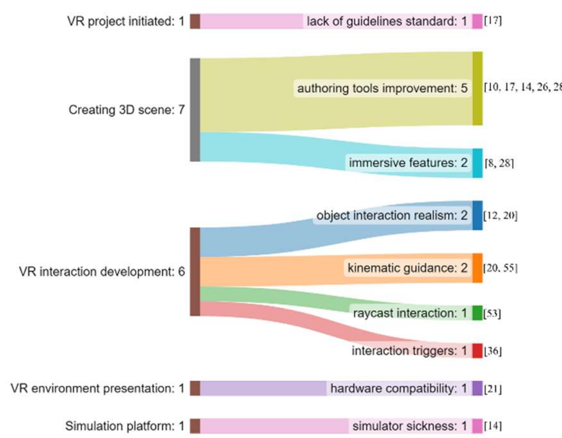

Figure 2: The Issues within the Pipeline

4.1 Authoring Tools

In the complex process of crafting captivating 3D scenes for VR applications, a critical facet involves challenges associated with the improvement of authoring tools. Authoring tools serve as the digital palette through which immersive landscapes of the virtual realm are molded and shaped. Nowadays, HCI research has explored new design approaches and tools specifically for VR applications. This research has introduced numerous authoring tools for both augmented reality (AR) and VR, showcasing a range of prototyping techniques, including physical prototyping methods [10, 24], immersive authoring [25], video-based editing [26], and asynchronous/asymmetric collaboration [27].

Despite the progress made in developing advanced authoring tools, designers are still encountering many challenges due to the need for specialized programming skills, particularly when it comes to designing immersive interactive experience [8]. High-end authoring tools like A-Frame, Unity and Unreal Engine are considered advanced and challenging for beginners to use. In contrast, simpler tools with more accessible interfaces and automated features are more approachable for a wider range of designers. However, this reduced learning curve and complexity also typically results in a trade-off, limiting the level of fidelity and control that can be achieved compared to the more complex professional-grade tools. Low-fidelity prototypes tools generally demand less specialized programming knowledge from the user. In contrast, creating high-fidelity prototypes requires more extensive programming skills, as these advanced prototypes need to be programmed directly.

The other challenges also are the complexity of user interface layout in the realm of VR authoring tools [28]. One example of the improvement is through dataflow programs in immersive authoring tools, supporting object customization such as group related elements [25]. The other related problem is the inadequate tool support and industry standards [24, 29] This deficiency is exemplified by [17] assertion that the AEC (Architecture, Engineering, and Construction) industry encounters limitations in available tools support despite being one of the sectors with the highest demand for VR system usage.

4.2 Realism and Presence

The virtual environment presentation with interaction model design principles and guidelines are had been proposed [30] and it keeps on growing [31-34]. The challenge of creating a seamless and immersive experience for users [12]. The challenge includes experience includes a lot of aspects such as sense of presence, realistic task involvements, and intuitive interactions and behaviors [35]. One way to achieve realism and presence in VR application is to determine based on to what extent the interaction fidelity. Interaction fidelity denotes the extent to which the system accurately reproduces real-world interactions [36]. The success and utility of a VR system is heavily reliant on how realistically and faithfully the virtual world can replicate the real-world environment being simulated [19, 37].

There are four levels of fidelity in VR namely first class, second class, third class and fourth class. *First Class Level* - Paper prototype and basic VR scenes. The utilization of paper prototypes offers a simple, cost-effective, and adaptable approach to developing interactive prototypes suitable for user testing. In addition, the use of 360-degree photos and videos has become increasingly popular for creating immersive experiences [20]. This approach is particularly effective for traditional mobile interfaces. Users can easily upload 360-degree photos to generate immersive scenes and define fundamental interactive functionalities using image maps [38] with anchors and trigger menus, or load other scenes. Consequently, VR previews are compatible with Google Cardboard [39].

Second Class Level - VR focused interactions. Platforms such as Facebook's AR Studio and Snapchat's Lens Studio empower users by providing access to libraries of trackers, 2D/3D objects, video masks, and animations. Users can leverage these resources to create interactive and shareable camera effects that respond to people and objects in their environment [13]. Additionally, these platforms offer support for visual programming, enabling users to add basic animations, logic, and interactivity to their VR experiences.

Third Class Level - 3D content. In the third class, users can work with 3D content by exporting objects in common 3D file formats, a capability shared with tools in other classes except the first. Additionally, there is an emphasis on leveraging 3D content sharing platforms such as Google's 3D Warehouse and Poly. These platforms have experienced significant growth, driven by the rising demand for 3D content arising from emerging technologies like 3D printing and virtual reality [40].

Fourth Class Level - 3D games and applications. Level fourth class fidelity in 3D games and applications refers to a higher level of detail and realism in VE compared to lower fidelity levels. In this level, developers focus on enhancing visual fidelity by incorporating advanced graphics techniques. By mimicking real-world movements, high-fidelity VR can improve a user's sense of touch and body awareness (proprioception), distance perception, and overall immersion in the virtual world [41].

Higher fidelity would be the most beneficial for virtual application due to resemblance to the realistic interactions of the real world [23, 42]. The high-fidelity is strongly related to better interaction, e.g., precise grabbing, rotating, and scaling of objects, can create a stronger sense of presence and engagement for the user. However, the challenge for high fidelity lies in striking a delicate balance between the visual appeal, haptic feedback, and the technical difficulties to deliver an immersive and realistic VR environment presentation [13]. This includes ensuring that the angle of view offers a natural perspective, facilitating seamless three-dimensional interactions, and implementing accurate head and body tracking are crucial components. One can increase the realism interaction in the high-fidelity VR by incorporating the multi-user feature [40].

Meanwhile, low fidelity prioritizes usability concerns, focusing on efficiency for faster task completion [43], an elusive indicator for high-fidelity [44]. Figure 3 illustrates the disparities among previous studies about level of fidelity and efficiency in development VR applications. It shows that the study for high fidelity VR application with high efficiency in task completion is limited, a gap that can be explored in the future.

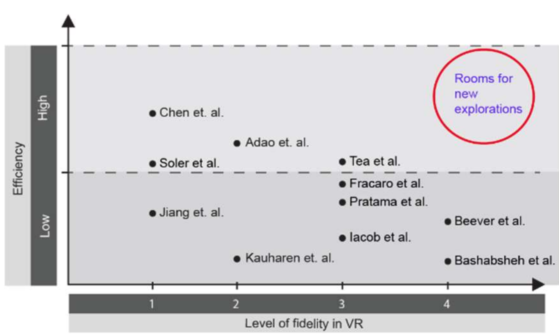

Figure 3: Prior Research Categorized According to the Level of Fidelity and Efficiency

4.3 Interaction Triggers

Table 3 summarizes the advantages and disadvantages of interaction triggers. There are two categories of input methods which are natural (hand, head, speech) and hardware based. The most immersive VR is when the interaction involves natural input method. However, the natural input method is always prone to fatigue. Meanwhile the hardware-based could give more satisfaction and good experience since it will provide faster feedback for interaction with the virtual objects. However, the hardware-based is prone to error since the hardware always involves sensors. It is worth noting that the interaction input and triggers depend on device compatibility.

4.4 Hardware Compatibility

In VR development, the choice of hardware is crucial for shaping the user experience. The hardware choice is also a main reason for the interaction input capabilities such as hand gestures, head movements, and speech recognition. The choice of hardware, such as head-mounted displays (HMD) and tracking systems, becomes crucial in addressing these challenges and delivering the intended immersive features. Device six degrees of freedom (6DoF) tracking capability, which provides both rotational and positional tracking. The 6DoF capability enables virtual objects to be moved in a more natural and intuitive way, as if they were being interacted with physical objects in the real world. In contrast, devices that only offer three degrees of freedom (3DoF), which is limited to rotational tracking, will not be able to provide the same level of realism and immersion for object manipulation tasks. Without the ability to translate objects in 3D space, the interactions will be felt as more constrained and less natural, potentially compromising the overall user experience. However, for whole-body movements within the VR environment, a moderate level of interaction fidelity may be deemed sufficient, as there is said to be a trade-off between realism and usability that needs to be considered [45]. Therefore, the selection of appropriate hardware is integral to overcoming the challenges associated with immersive features in VR development.

Other devices are low-cost HMD through smartphones, e.g., Google Cardboard and personal computer (PC). The interaction is limited for low-cost HMD but can be rich in PC. However, it is not possible to incorporate with also low-cost controllers as the interaction solvers that will also increase the experience of the VR application [46-48]. Besides, today smartphones are quite high in spec, we can explore a little recognition program in let say VR/AR ray casting system using image recognition on a smartphone. to be implemented for hand grabbing, or rotating recognition though the smartphone. Although PCs is also rich in interaction where user can use mouse and keyboard for VR application such as watching 360° videos, however users tend to be in the idle state without changing the viewport for a longer duration than using HMDs and smartphones [49, 50]. It shows that with PC, user fell less interest compared to either normal HMD or low-

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cost HMD. Today, smartphone's technical specification are high, therefore we can explore more into recognition program in VR/AR ray casting system using image recognition on a smartphone to be able to control objects in VE such as grabbing and or rotating [51].

4.5 Simulation Sickness

Despite significant progress, several challenges persist in the study of motion sickness in VR. Understanding the wide variability in susceptibility to motion sickness among users remains a challenge due to factors such as age, gender, prior VR experience, and individual physiology. This variability makes it difficult to predict and effectively address motion sickness in VR experiences. Additionally, many studies on motion sickness in VR are conducted under controlled laboratory conditions, limiting the generalizability of findings to real-world scenarios. Generalizing results from controlled experiments to diverse VR applications and user populations poses challenges in accurately assessing the prevalence and impact of motion sickness. Identifying personalized interventions tailored to individual characteristics and preferences presents a particular challenge in addressing motion sickness effectively across diverse user groups and VR application is crucial

The complex mechanisms underlying motion sickness in Virtual Reality (VR) pose a significant challenge, as they are not fully understood. While discrepancies between visual and vestibular stimuli are recognized triggers, the specific neural processes involved in motion sickness in VR are still being elucidated. Additionally, the long-term effects of repeated exposure to VR and motion sickness remain poorly understood. Studies exploring potential habituation effects or lingering symptoms after VR use are essential for informing guidelines aimed at ensuring safe and sustainable VR experiences. Addressing these challenges requires further research to deepen our understanding of the mechanisms driving motion sickness in VR and its potential long-term implications for users.

Firstly, offering users the choice between traditional locomotion methods and teleportation can cater to individual preferences and comfort levels. Smooth transitions between scenes or movements help prevent abrupt changes that may trigger discomfort, while incorporating visual cues within the environment aids in maintaining spatial orientation.

Secondly, providing options to reduce the field of view during rapid movements or rotations can lessen the sensation of motion. Customizable comfort settings allow users to tailor their experience, while real-time feedback mechanisms enable adjustments based on user comfort levels. Gradually exposing users to VR experiences and environments can help acclimate them and reduce the likelihood of motion sickness. By combining and incorporating these different interaction techniques, developers can develop VR experiences that are more inclusive and provide a more enjoyable experience for users.

While various mitigation strategies have been proposed, determining the most effective approaches for minimizing motion sickness in different contexts remains an ongoing area of research. Addressing these challenges requires interdisciplinary collaboration between researchers in fields such as neuroscience, psychology, human-computer interaction, and VR development. By combining insights from diverse disciplines and leveraging advancements in technology and methodology, researchers can work towards a deeper understanding of motion sickness in VR and the development of more effective mitigation strategies, and probably will end with a cure of motion sickness, hence completely solve this problem.

5. DISCUSSION

We discovered the fundamental challenges surrounding immersive interaction design in the development of VR applications. In particular, we have identified five key scientific problems that developers should consider to improve the quality of VR experiences future VR research, aiming not only improving the VR technology but also aiming at bring peace and prosperity for future sustainability. In this section we are going to discuss the five problems and show how to tackle them for the SDGs.

Future research on developing less complex VR authoring ecosystem is essential to address the unique requirements of virtual environments. The research should focus on creating advanced, user-friendly VR authoring tools that facilitate collaborative content creation. a collaborative authoring can significantly lower barriers for diverse stakeholders. The process should be streamlined by these tools, and real-time cooperation should be enabled. Users with varying technical expertise should be empowered to contribute effectively through VR content creation and their positive feedbacks improving the ecosystem. This can be enhanced when more research on how can the tool provide more appealing immersive interaction design capabilities such as able to visualize the programming through a simple visual representation, so that the user can easily understand how the immersive interaction works at the first glance. Besides, a light-weight type of VR software should be provided so it can be downloaded and used in online or offline mode, especially for developing countries and least developed countries. All their works can be aligned to the SDGs #9 where it can promotes inclusive and sustainable industrialization and foster innovation for those countries. Comprehensive Guidelines for designing immersive interaction also should be emphasized.

Another research is the creation of realistic VR environments with intuitive input methods. It is a higher-level fidelity of VR which has been envisioned in “Radical Atoms” a term that brings the virtual object into the real world. This can promotes SDGs #9, the inclusivity and fostering community engagement in sustainable development efforts. However, the higher the level of the VR fidelity, the difficult the task is going to be. To achieving higher level of realism and interaction, one require to overcoming technical limitations such as graphical fidelity, spatial audio, haptic feedback, temperature generation, and olfactory, to enhance realism of the virtual objects in the real life. The challenge will be much more challenging when no wearable is applied to the user. The research can also focus on enhancing the user experience through input modalities such as vision tracking, voice commands, haptics and artificial intelligence (AIs). By exploring more alternative interaction triggers such as voice commands and gesture recognition, we can democratize access to VR experiences and empower all individuals, with diverse abilities and preferences, to participate actively in sustainable development initiatives. For instance, the interaction with the NPCs who are living in the virtual world (VW) in the meantime know and understand what currently everything in our real life since its knowledge can evolve as the real world evolve. This AI NPCs interaction can improve education in SDG #4 where is promotes quality education and lifelong learning opportunities.

Hardware, software compatibility, and VR immersive interaction design guideline challenges are also an open research opportunity for immersive interaction design. The VR system should be more user friendly and compatible with a broader range of systems. It is crucial to consider practical and technical elements when designing immersive VR interaction technologies for diverse applications.

The ongoing advancements in VR hardware require continuous adaptation and optimization to leverage emerging capabilities while maintaining backward compatibility with existing devices. A research on standard for multiplatform where a minimum requirement for every platform should be carried out. This situation can be seen as what happened in the world-wide-web today, a standard www where it is a standard that is widely accepted by the public for share and interact with the information globally. It is a form of a backbone of how we interact with online content today. This should happened same to the VR, where it is capable to be used by anyone on any device at anytime including the Low-cost HMD device such as the Google Cardboard. This is also aligned with SDGs #9 where it can promotes inclusive and sustainable industrialization and foster innovation for those countries.

Lastly, research on simulation sickness in VR usage is also vital. The sickness imposes discomfort and restrict the usability of VR systems. This will result of the reclination of VR usage in the future. Factors that contributing to simulation sickness include latency, visual artifacts, and discrepancies between perceived and actual motion. By prioritizing user comfort and safety in VR design, researchers can mitigate adverse effects and promote sustainable usage practices. Mitigating simulation sickness requires a multifaceted approach encompassing optimization of rendering pipelines, refinement of locomotion techniques, and user-centered design practices that prioritize comfort and safety. Moreover, fostering awareness and education about simulation sickness can empower users to navigate VR environments responsibly. Another direction could be exploring adaptive VR experiences. For example, VR experiences that can automatically adjust to individual user sensitiveness. This approach could involve artificial intelligence (AI) systems that learn user preferences, for example, if the user have been identified as a person that is suffering with motion sickness, then the navigation in the VR experience would be teleport instead on sliding. Developing cross-platform comfort would also able to ensure consistency across VR applications. This is aligned with the SDGs #3 where it can promotes good health and wellbeing for anyone that are using VR (i.e., with sickness or no sickness). These research opportunities can result in

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the creation of immerse VR experience to be more accessible and impactful.

6. LIMITATION

One limitation of our study is that it primarily focuses on the perspective of VR creators during the rapid prototyping phase. Future research should expand upon our findings by examining the high-fidelity VR development process.

7. CONCLUSION

In conclusion, our study has explored the prevalent issues and hurdles within the dynamic realm of VR application development. Addressing this challenge entails a holistic approach integrating advancements in hardware, software, and human-centered design principles to foster compelling and believable VR experiences. By scrutinizing existing literature, we have pinpointed five scientific challenges within the VR development pipeline, particularly concerning interaction design. Overcoming these main obstacles is essential for harnessing the full potential of immersive technology as a catalyst for sustainable development. The insights from our analysis can unlock the transformative power of VR, fostering innovation and driving positive change towards a more inclusive and sustainable future for all.

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Authors' contributions

Nurul Aiman, Mohd Adili and Zulisman responsible for the conceptualization of this paper. Nurul Aiman took the lead in writing the paper. Mohd Adili provided supervision and guidance through the writing process. All authors provided critical feedback, proofreading and reviewed before submission.

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Table 2: Key Stages in VR Application Development Related

Authors and related keywords	Key stages				
	VR project initiated	Creating 3D scene	VR interaction development	VR environment presentation	Simulation platform
Realism Enhancement [52]	✓	✓		✓	
Interaction design [53, 54]	✓	✓		✓	
Presence and Immersion [55]	✓	✓			✓
Spatial Audio [56]		✓	✓	✓	
Performance Optimization [57]					✓

Table 3: Key Stages in VR Application Development Related

Input Method	Advantages	Disadvantages
Hand	• Can be enhanced by combining it with hardware-based techniques to improve the performance of manipulation tasks (translation/rotation/scale) [58] • Ease to use [58-60] • Can be carried out on either the front or the back side of the device [58] • More engaging and immersive experience when interacting with objects at close proximity [59, 60]	• Directly interacting with and manipulating virtual elements by hand-occlusion [58] • Significantly slower when compared to the screen dwell technique [60] • Not always practical to use because users typically need at least one hand to hold the device, and it can lead to user fatigue [58, 59]
Head	• Effective at allowing the user to indicate or designate particular objects or regions within the interface or environment [60] • Can help reduce the time needed to complete abstract voice commands, as the interaction requires shorter and less detailed voice inputs [60]	• Affected by distance/location of targets (too close or too far) [60] • Requires holding phone in unnatural position to capture head directionality information [60] • System requires the user to go through a learning process and invest time to become skilled (McLean, 2021)
Speech	• Effective for Abstract/menu-based interactions and has a lower workload than hand/hardware-based input [60] • Can be used to improve interaction experience/provide more interaction capabilities [61]	Requires the user to make longer and more precisely articulates voice commands [60]
Hardware-based	• Raycasting techniques are quick and effective for pointing at selecting largeof visible content [62, 63] • Hardware-based gestures (6-dof) provide an intuitive and natural method for controlling objects or characters through translation, rotation, and scaling [64] • Separating touch and motion inputs into independent mechanisms (i.e. for pointing/selecting or translation/rotation) can improve the overall usability of the system [65] • Traditional touchscreen gestures are generally easy and comfortable for users to employ when performing simple object manipulation tasks [66]	• Multitouch/motion gesture interaction is often more cumbersome for tasks like selection /object manipulations (translation/rotation/scale) and they are prone to errors, mainly due to issues likefinger occlusions/sensor tracking [32, 58, 66] • Raycasting techniques are less effective for pointing/selecting when the targets are are occluded or small [63] • Touchscreen/motion gestures generally require a higher cognitive workload task-load compared to voice or gaze-based interactions [67] • The precision of hardware-based techniques for selection and object manipulation is heavily dependent on type of interactive content and the design of output [62] • Motion-based inputs often require system adaptations such as user perspective rendering [32] to enable usable interactions for rotation tasks, as well as target expansion to facilitate pointing/selecting and menu-based interactions [68] • Touchscreen-based interaction does not accurately mimic object manipulations [59], and when used alone, it can limit the overall in in the real world [58, 61]