An Empirical Study on Current Practices and Challenges of Core AR/VR Developers

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Abstract

Augmented reality (AR) and virtual reality (VR) applications are increasingly integral to modern society. Core AR/VR developers, pivotal in crafting these advanced technologies, face significant challenges throughout the software development lifecycle. In this context, 'core AR/VR developers' refers to professionals who actively engage in developing AR/VR technologies, including researchers and developers. We surveyed such professionals to directly understand these challenges and received 48 responses. Our findings categorize the unique challenges into three major stages of SDLC - *Design, Implementation, Testing* that core AR/VR developers pointed out. These challenges include creating immersive experiences, complexity in 3D interaction, cross-platform compatibility, and reproducing bugs. This study highlights significant AR/VR development obstacles and provides foundational insights for future research to improve development practices and tools in this rapidly evolving field.

CCS Concepts

• **Human-centered computing** → **Mixed / augmented reality**; **Virtual reality**; • **Software and its engineering** → **Programming teams**; Application specific development environments.

Keywords

empirical study, augmented reality, virtual reality, open coding

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1 Introduction

Augmented and Virtual Reality (AR/VR) technologies have expanded beyond gaming [1] and entertainment [2], influencing sectors such as advertising [25], education [17], military [28], and healthcare [30]. Their usage in both private [33] and public [15] settings reflects a deeper integration into everyday life, serving functions ranging from educating special needs children [24] to aiding in medical diagnoses like Parkinson's disease [20]. AR/VR developers, central to creating these diverse applications, are tasked with implementing, testing, and maintaining software across various domains.

The software development lifecycle (SDLC) is essential for organizing AR/VR development efforts, encompassing requirement analysis, design, implementation, and testing. With the rise in AR/VR applications and new device availability, more developers are engaged in this field [26]. Previous studies have explored the challenges of end-user programmers and the collaborative practices in interdisciplinary teams [5, 19]. While the importance of collaboration is well-recognized, to our knowledge, no study has specifically explored the unique challenges faced by core AR/VR developers, a critical group within this ecosystem. We define *"core" AR/VR developers* as professionals primarily engaged in AR/VR application development, with this area being their main field of expertise. This contrasts with *regular AR/VR developers*, who may engage with AR/VR technologies intermittently or as a secondary aspect of their roles, often without specialized training in AR/VR development. It is crucial to gain insight from core AR/VR developers to understand challenges that impact interactive collaboration and communication within the AR/VR development process.

We designed a study to understand specific challenges faced by software developers unique to AR/VR development. In our work, we seek to answer the following research questions:

RQ1: What challenges do core AR/VR developers face at different stages of the SDLC?

RQ2: How do developers overcome challenges related to AR/VR development?

We conducted an online survey with 48 diverse AR/VR developers and analyzed the data using open coding to understand the key challenges in mixed-reality development. Our findings reveal unique challenges in three major stages of software development life cycle (SDLC) [29]: *Design, Implementation, Testing*. This study systematically categorizes these challenges and offers insights into effective strategies employed by developers. The results are informative for researchers and practitioners, suggesting ways to improve AR/VR development processes.

By bolstering the previously published relevant efforts by Ashtari et al. [5], Krauß et al. [19], and Speicher et al. [32], our paper contributes the following:

- An empirical analysis of the challenges unique to AR/VR development during different SDLC life cycles.
- Insights into how AR/VR developers handle these unique challenges.

2 Background and Related Work

Previously, researchers conducted studies to discover the barriers that AR/VR developers face at different levels. Krauß et al. [19] found

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relations between AR/VR creators' roles while developing extended reality (XR) applications. The term extended reality includes AR, VR, mixed reality (MR), and everything in between them [9]. They provided information about collaborative work methods for cross-disciplinary AR/VR application development. Nebelling et al. [12] stated issues related to AR/VR authoring tools and highlighted the need for authoring tools that do not rely on coding skills. Ashtari et al. [5] pointed out barriers end-user developers faced while creating an AR/VR application. End-user programmers are developers from various disciplines who learn to create code to supplement a task they are given in their academic or professional environments or just for fun [23].

Development from end-users is a core topic of study in the HCI community [18], [6]. Gandy et al. [14] conducted study on Designer's Augmented Reality Toolkit (DART) developers to find out how non-technologists can develop XR applications effectively. Recently, based on two sample situations, Speicher et al. [32] highlighted six major challenges in AR applications, including narrow field of view, gesture recognition, etc. In sum, Ashtari et al. [5] discussed barriers from the perspective of end users, Krauß et al. [19] pointed out the challenges of interdisciplinary AR/VR development, and Speicher et al. [32] highlighted the shortcomings of cross-platform AR applications. To our knowledge, no work focuses on finding the barriers that core AR/VR developers face within different contributors, including documentation writers, testers, developers, etc. In this study, we focus on this gap.

3 Study Design

We conducted a survey to understand AR/VR development practices and challenges, gathering information from 48 experienced AR/VR developers about ongoing issues.

3.1 Survey Design

Our survey was structured to explore three major software development lifecycle phases (SDLC) phases-*Design, Implementation, Testing* [29], aiming to capture insights into prevailing issues within AR/VR development. The questionnaire was segmented into sections, beginning with initial questions that collected demographic data, professional experience in AR/VR development, and participants' current roles in the industry. These initial inquiries were essential to ensure responses from seasoned AR/VR developers deeply engaged in current mixed reality projects and technologies.

Ten of the questionnaires were dedicated to free-response questions. Subsequently, the survey delved into more specific inquiries tailored to both AR and VR sectors, assessing the types of devices developers utilize and the environments in which they operate. These were designed to uncover the unique challenges developers face during the design, implementation and testing phases of AR/VR applications. To validate the pertinence and comprehensiveness of our survey, it underwent a review and received approval from the Institutional Review Board (IRB) of our institution prior to distribution.

3.2 Participants

We circulated our survey to online social media platforms, including AR/VR developer communities on Facebook,[1] LinkedIn,[2] and Discord.[3] We received responses from a diverse group of 48 core AR/VR developers. Among our participants, 35 (73%) identified as male and 13 (27%) identified as female. Participants had at least four months of AR/VR development experience and a maximum of seven years. On average, participants had 2 years of development experience with a median of 2.2 years. All of our survey participants work in AR/VR industry with diverse roles, including Associate Extended Reality (XR) Developer, Senior XR Developer, Junior XR Developer, Team Lead, AR Researcher, and XR Researcher at companies such as AIVerse, Deloitte, Sigmoid AI, Bosch Rexroth, Megagon Lab, and the authors' primary institution. Among the responses, 23 developers work only in AR applications, 18 only in VR applications, and 7 in both AR and VR. In Tables 1 and 2, we show our survey participants' percentage of devices used for AR/VR development and the general domain of AR/VR applications they develop. We found the purpose of AR/VR applications implemented by participants spans various domains, including entertainment, education, healthcare, and business.

Table 1: AR/VR Devices used for development by survey participants

Device Name	Number of Responses
HTC Vive	15
HoloLens	11
Magic leap 2	9
Varjo XR-3	9
Mobile applications*	5
Oculus Quest	3
Samsung gear VR	2

*Here, mobile application means AR/VR applications designed for smartphones. Participants worked with multiple devices so the number does not add to the total participants.

Table 2: Domains of AR/VR applications our survey participants

Application Type	Number of Responses
Entertainment	19
Business-related	13
Medical-oriented	11
Educational	8
Research prototype	5
Health	2
Financial	1
User study	1

*Participants worked in multiple domain, so the number does not add to the total number of participants.

[1]https://www.facebook.com/
[2]https://www.linkedin.com/
[3]https://discord.com/

3.3 Data Analysis

To categorize challenges in collaborative scopes, SDLC phases, and AR/VR-specific barriers, we used a qualitative open coding technique [11], effective in domain-specific empirical research [3, 4].

Two experienced raters in AR/VR and software engineering independently coded the responses, following these steps:

- The rater read responses carefully and highlighted keywords from each response
- Based on given keywords, they assigned a theme to the given statements individually;
- Based on the given theme, raters categorize responses.

Discrepancies were reconciled through detailed discussion, ensuring the final categorization reflected the data's complexity. Cohen's Kappa coefficient [10] measured inter-rater agreement before alignment discussions, providing an estimate of coding consistency.

4 Presentation of results

4.1 RQ1: Unique Challenges identified by Core AR/VR Developer

The primary objective of our first research question is to identify the unique challenges in major AR/VR development stages. Following the methodology outlined in Section 3.3, we achieved a Cohen's Kappa score of 0.83 for our open coding, indicating an "almost perfect agreement" according to Landis and Koch [21]. In Figure 1 , we illustrate unique challenges for each SDLC phase with number of responses.

4.1.1 Design: **Immersive Experience Design**: Creating an environment that feels truly immersive and engages all the senses is a major challenge in AR/VR development. As one participant shared, "Making an experience that feels real and engaging for users is tough. It's not just about visuals but about making it feel immersive across all senses" [P15].

Scalability of Design: Ensuring that designs work well across various AR/VR devices and platforms while maintaining a high quality can be quite challenging. One participant explained, "It's really hard to make sure a design looks and works great on every device. Different devices mean different challenges" [P22].

4.1.2 Implementation: **Handling High-Dimensional Data**: Managing and processing large amounts of complex data in AR/VR applications can be a significant hurdle. One participant noted, "Dealing with all the data from sensors and depth maps without slowing things down is a big challenge" [P9].

Cross-Platform Compatibility: Ensuring that an AR/VR application works consistently across different hardware and operating systems involves a lot of effort. One participant mentioned, "Making sure the app works well on different devices and platforms is a real struggle. Each one has its own quirks" [P30].

3D Interaction Design Complexity: Designing natural and intuitive interactions in a 3D space is particularly complex. As one participant pointed out, "Getting 3D interactions to feel natural and intuitive is really hard. It's not like working with 2D where things are simpler" [P18].

4.1.3 Testing: **Knowing the Output Beforehand**: Predicting and understanding the exact output of AR/VR applications can be challenging due to their dynamic and interactive nature. One participant shared, "It's often hard to anticipate what the app will do in different scenarios. For example, when testing a VR game, it's tough to predict how different actions will affect the virtual environment" [P44].

Bug Reproduction: Reproducing bugs in AR/VR applications can be particularly difficult due to the variability in user interactions and environmental factors. A participant explained, "Reproducing a bug is really tricky. For instance, a certain glitch only happens when users interact with specific objects in a particular sequence, which is hard to recreate consistently during testing" [P12].

Environmental Variability: Testing AR/VR applications in varied environments can introduce unforeseen issues that are difficult to replicate. One participant described, " I once had a problem where a feature worked fine in the lab but failed in a different setting with natural sunlight" [P27].

4.2 RQ2: Approaches for Overcoming Challenges in AR/VR Development

In Section 4.1, we explored the unique challenges within the AR/VR software development lifecycle identified from developer responses. For RQ2, we investigate the strategies developers employ to overcome these challenges.

We found that developers primarily rely on Q/A websites, developer forums, and device-specific documentation when facing difficulties, as shown in Figure 2. Platforms like Stack Overflow[4] and Stack Exchange[5] allow community-driven problem solving, while developer forums such as Magic Leap's online platform[6] offer device-specific support. Documentation for development tools such as Unity[7] and WebXR[8] provides detailed feature and library descriptions.

Our survey data is summarized through set operations indicating the overlap of resource usage: - Only Q/A websites: = 15 (31%) - Only documentation: = 12 (25%) - Only developers' forum: = 8 (17%).

4.2.1 Current Measures to test AR/VR applications. We also asked the developers to provide insight into their approaches to test AR/VR applications. We demonstrate our findings in Figure 3 where nineteen developers reported using a simulator for specific devices, fifteen using existing testing options within their integrated development environment (IDE), and fourteen by deploying software to the actual device and then testing.

5 Discussion

5.1 Advancing AR/VR Developer Support

Our findings highlight significant design and implementation challenges in AR/VR development. Immersive experience design and design scalability are critical, requiring developers to create highly engaging and consistent user experiences across devices, echoing

[4]https://stackoverflow.com/
[5]https://stackexchange.com/
[6]https://forum.magicleap.cloud/
[7]https://unity.com/
[8]https://immersive-web.github.io/webxr-samples/

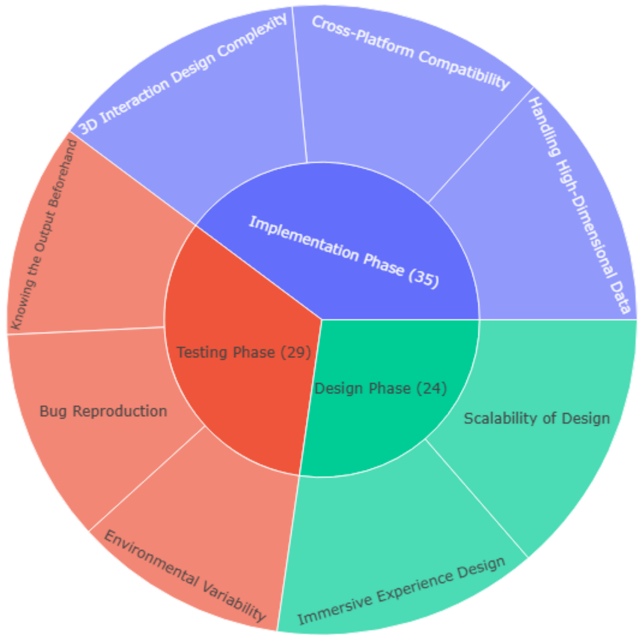

Figure 1: Unique challenges within stages of AR/VR application development

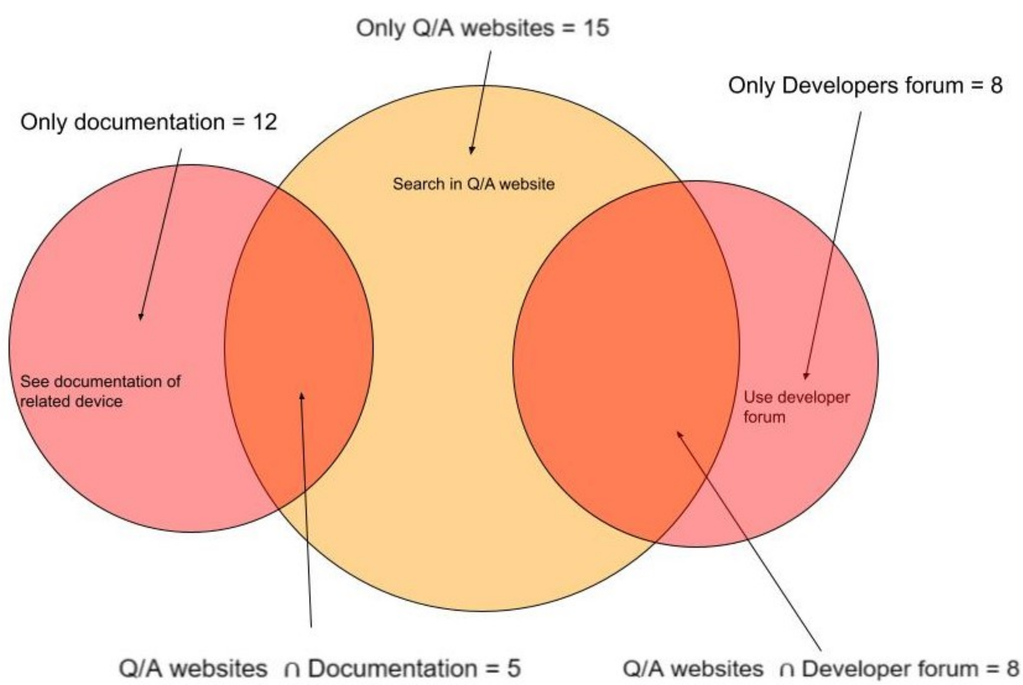

Figure 2: Measures developers take when facing challenges

findings by Charkaoui et al. [7]. Handling high-dimensional data and ensuring cross-platform compatibility pose substantial implementation difficulties, necessitating efficient data management and adaptability to various hardware. Moreover, the complexity of 3D interaction design demands intuitive and responsive user interfaces. Addressing these challenges, we recommend developing advanced

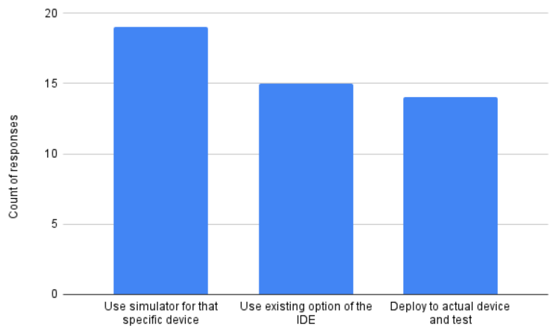

Figure 3: Testing approaches for AR/VR applications

tools and techniques to support AR/VR developers, such as improved debugging tools for high-dimensional data and cross-platform testing frameworks [9]. Additionally, leveraging user interaction recordings and pattern identification can enhance the design and implementation processes, leading to more robust and user-friendly AR/VR applications.

5.2 Enriching Effective Measures for Testing

We uncovered the challenges and measures developers take to test AR/VR applications. Correa et al. [31] proposed VR-ReST for functional testing, using a semi-formal language to specify requirements and generate test cases. Fang et al. [13] highlighted the necessity of human participation in usability testing and used a modified feedback system to gather user feedback. Lehman et al. [22] developed *ARCHIE*, which generates test logs automatically based on inputs and outputs for interface testing. Ashtari et al. [5] emphasized the need for interactive testing tools from the end user's perspective in AR/VR applications.

Key challenges in AR/VR testing include knowing the output beforehand, bug reproduction, and environment variability, highlighting the need for tools that automate and verify these tasks. Recording user interactions and identifying patterns can improve testing, while advanced debugging tools can enhance bug reproducibility and localization. Ikeda et al. [16] proposed ARHMD for AR robotics, detecting bugs in code, hardware, and sensor data. Metamorphic testing [8], a property-based technique, can assess software quality by examining input-output relations, reducing dependency on predefined outputs.

6 Future Work

Future research should focus on developing support tools for AR/VR that streamline user feedback collection and enable functional testing within immersive environments. Investigating code translation between devices using large language models is also promising [27]. Comprehensive test suites and development tools tailored for AR/VR contexts are needed to address challenges like body movement and immersion.

[9] https://docs.unrealengine.com/

7 Conclusion

Augmented and virtual reality (AR/VR) applications are becoming increasingly prevalent and complex. Our empirical study focuses on core AR/VR developers, surveying 48 participants with experience developing and maintaining AR/VR applications to understand the specific challenges they face throughout the software development lifecycle, particularly in the Design, implementation and testing phases. We identified key areas of challenge: Immersive experience, Scalability, Handling high-dimensional data, Cross-platform compatibility, and Development Collaboration, along with bug reproduction. Each area presented unique issues involving stages of SDLC phases, which core AR/VR developers mention. Our findings highlight the urgent need for tools and resourcunderscore the need for innovative approaches thato integrate AR/VR-specific requirementthese specialized needs into standard SDLC processes, urging researchers to develop innovati. This includes developing new resources and tools that can better support the creation and maintenance of sophisticated AR/VR applications. Researchers and tool developers are encouraged to focus on these gaps, proposing novel solutions that enhancecould significantly enhance the effectiveness and efficiency of AR/VR development practices.

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