



Transforming Finance: A VisionOS-Backed Banking App with Intelligent Insights

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Dedictory

I dedicate this work to God, for guiding me every step of the way, and to my family, for their constant love and support.

I also want to thank my friends for always encouraging me, my colleagues for their help along the way, and my supervisor for the guidance and advice that made this project possible.

Abstract

This thesis presents a study on the development of a version of ebankIT's mobile banking application for Apple's VisionOS. The work explores the potential of augmented reality (AR) and virtual reality (VR) technologies in the banking sector, focusing on the creation of a new application for this immersive platform, without modifying the existing iOS version.

The study begins with an analysis of current trends in digital banking, highlighting the growing relevance of immersive technologies in financial services. It then explores the specific characteristics of VisionOS, Apple's new platform for AR and VR, evaluating how its functionalities can be leveraged to improve the user experience in the new digital banking application.

The research objectives include a technical analysis of the development process for the VisionOS application, with a focus on the adaptations needed to make the most of its immersive features. The thesis discusses the development of a prototype in VisionOS, demonstrating how AR and VR can provide more intuitive interactions for users in a banking context. Features like gesture controls and interactive interfaces are explored, taking advantage of VisionOS's capabilities.

Furthermore, the study addresses the challenges and solutions encountered during the development of this new version of the application for VisionOS, with a focus on the opportunities presented by the platform.

The thesis concludes with a reflection on how VisionOS might impact the future of digital banking, offering a more immersive and interactive experience for users. The new application illustrates how AR and VR platforms can influence the way users manage their finances.

Through this research, the thesis aims to contribute to the field of financial technology, providing insights for banks and developers interested in exploring the potential of immersive platforms like VisionOS to create new digital experiences.

Keywords: VisionOS, AR, VR, Banking Application, User , UX, OpticID, Gesture Controls, AI, FinTech, Immersive Technologies, Security in AR/VR, Biometric Authentication, Virtual Assistant, Spatial Computing, User Interaction Design, SwiftUI

Resumo

Esta tese apresenta um estudo sobre o desenvolvimento de uma versão da aplicação de mobile banking da ebankIT para o VisionOS da Apple. O trabalho explora o potencial das tecnologias de realidade aumentada (AR) e realidade virtual (VR) no setor bancário, focando na criação de uma nova aplicação para essa plataforma imersiva, sem modificar a versão existente para iOS.

O estudo começa com uma análise das tendências atuais no digital banking, destacando a crescente relevância das tecnologias imersivas nos serviços financeiros. Em seguida, explora as características do VisionOS, a nova plataforma da Apple para AR e VR, avaliando como suas funcionalidades podem ser utilizadas para aprimorar a experiência do usuário na nova aplicação de banking digital.

Os objetivos da pesquisa incluem uma análise técnica do processo de desenvolvimento da aplicação no VisionOS, com foco nas adaptações necessárias para aproveitar as funcionalidades imersivas. A tese discute o desenvolvimento de um protótipo no VisionOS, demonstrando como AR e VR podem proporcionar interações mais intuitivas para os usuários no contexto bancário. Recursos como controles por gestos e interfaces interativas são explorados, aproveitando as capacidades do VisionOS.

Além disso, o estudo aborda os desafios e soluções encontrados no desenvolvimento dessa nova versão da aplicação para o VisionOS, com foco nas oportunidades oferecidas pela plataforma.

A tese conclui com uma reflexão sobre como o VisionOS pode impactar o futuro do digital banking, proporcionando uma experiência mais imersiva e interativa para os usuários. A nova aplicação mostra como plataformas de AR e VR podem influenciar a forma como os usuários gerenciam suas finanças.

Por meio desta pesquisa, a tese busca contribuir para o campo da tecnologia financeira, fornecendo uma visão para bancos e desenvolvedores interessados em explorar o potencial de plataformas imersivas como o VisionOS para criar novas experiências digitais.

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List of Acronyms

2D	Two-Dimensional.
3D	Three-Dimensional.
6DoF	Six Degrees of Freedom.
AI	Artificial Intelligence.
AR	Augmented Reality.
BPI	Banco Português de Investimento.
CPU	Central Processing Unit.
GPU	Graphics Processing Unit.
HPU	Holographic Processing Unit.
IMUs	Inertial Measurement.
JWT	JSON Web Token.
ML	Machine Learning.
MR	Mixed Reality.
MRTK	Mixed Reality Toolkit.
MVVM-C	Model-View-ViewModel-Coordinator.
SDK	Software Development Kit.
STEM	Science, technology, engineering, and mathematics.
UX	User Experience.
VR	Virtual Reality.

Chapter 1

Introduction

The aim of this introductory chapter is to introduce the reader to the context and situation in which the document was drawn up. It also aims to present the problem it is intended to solve, as well as the project's objectives.

This chapter will also give an idea of what the project will be like, as well as the structure of the document with a brief explanation of the content of each chapter.

1.1 Context

The digital transformation in the financial sector, particularly with the incorporation of Augmented Reality (AR) and Virtual Reality (VR), is redefining user experience (UX).

In the article (Patterson 2023), it discusses how AR enhances the user experience at point of sale. AR allows digital overlays in the physical world, providing additional product information and facilitating mobile payments through AR interfaces. This interactive approach significantly improves UX in financial retail environments. The article highlights AR's potential to transform how consumers interact with financial services, making the experience more informative and personalized.

In (Haritonova 2023), various practical applications of AR in the financial sector are explored. This article emphasizes how AR can be used to improve training and financial education, directly impacting the user experience. By making financial concepts more accessible and interactive, AR facilitates a deeper understanding and greater engagement of users with financial services.

ebankIT - Omnichannel Digital Banking Platform (ebankIT 2022), a company specializing in omnichannel digital banking platforms. Their focus lies in innovating and providing customer-centric, intuitive solutions that cater to the needs of financial institutions. ebankIT provides an omnichannel digital banking platform that offers innovative mobile banking solutions, focusing on a consistent and interactive experience across all channels. The platform is designed to be customer-centric, intuitive, and disruptive (M. B. S. ebankIT 2022).

VisionOS (Apple 2023c) is Apple's innovative spatial operating system designed to power the Apple Vision Pro headset. Introduced at the WWDC 2023, VisionOS marks Apple's entry into the realm of spatial computing, a computing form where digital content seamlessly integrates with the physical space. This operating system allows users to interact with digital content as if it were part of their real-world environment, bringing a revolutionary approach to computing.

1.2 Problem

In the rapidly evolving landscape of mobile banking, where user expectations in terms of convenience, personalization and seamless financial management are at an all-time high, there is a pressing need for innovative solutions that take advantage of cutting-edge technologies. The specific problem is the need to improve the user experience in mobile banking applications.

Banks and financial institutions face constant pressure to innovate, differentiating themselves through attractive and engaging user experiences (Chheda 2023). The article (Finextra 2023) emphasizes how AR and VR could significantly improve financial literacy and customer experiences in fintech. It discusses the potential of these technologies to provide educational tools through gamification, improve visualization of financial data, and allow customers to plan different financial scenarios in a virtual environment.

Also the problem at hand is the feasibility and impact of integrating Apple's VisionOS into ebankIT's mobile banking application. The challenge is to assess whether this advanced AR technology can enrich the user experience. On the business side, the question expands to analysing how this innovation can offer a competitive advantage in the saturated financial market.

The adoption of VisionOS could be a response to this demand, promising unprecedented immersion and interactivity. Using AR glasses, customers could, visualise financial information and analytical graphs in a three-dimensional space, making financial data analysis more intuitive and engaging (Cram 2023).

In addition, the use of AR glasses could bring benefits such as the convenience of accessing banking services from anywhere, with an additional layer of security provided by biometric authentication and facial recognition that devices such as Apple Vision Pro could offer. Another potential benefit is the advanced personalisation of customer service. AR technology could allow users to interact with a virtual advisor almost as if they were in a physical branch.

The proposed research therefore seeks to offer a analysis and an innovative solution that could set a new standard for the customer experience in mobile banking.

1.3 Objectives

The aim of this project is to develop a solution to the problem described in 1.2.

Evaluate Technical Integration - Determine a detailed technical analysis to ensure VisionOS can be integrated with ebankIT's existing mobile banking app infrastructure. It includes compatibility checks, dependency analysis, and identification of potential technical hurdles. The process would also involve a review of VisionOS's documentation, APIs, and any software development kits (SDKs) that Apple provides to support integration efforts.

Assess UX Enhancement - In this objective, the study aims to specifically determine how the AR capabilities of VisionOS can enhance the banking app's user interface and functionality.

Prototype Development - The development of a prototype serves as a practical step to explore the potential improvements VisionOS brings to the mobile banking experience. It will involve creating a working model of the ebankIT app with VisionOS integration to test specific functionalities, such as visualizing account information and transfer money.

Understand Market Trends - This objective encompasses researching and analyzing the latest trends in the financial technology industry that might influence or be influenced by AR and VR technologies.

1.4 Research Process

To begin the first step of the research process for the thesis was needed to identify and clearly define the research problem. The problem is the need to enhance the user experience in mobile banking applications using Augmented Reality (AR) and Virtual Reality (VR). During the literature review were used, ResearchGate, Google Scholar, Academia.edu, this platforms provided access to academic papers and articles, the search strategy included specific keywords such as **banking technology, bank innovation, future of banking, augmented reality in banking, virtual reality in financial services, user experience in mobile banking, metaverse in banking, metaverse applications in finance, AR/VR in the metaverse**. Emphasis was placed on recent publications, preferably from the last five years, to ensure up-to-date relevance. It offered insights into current technological advancements and trends in AR and VR, especially their application in banking and financial services. Mixed-Methods Research was chosen because it combines the strengths of both qualitative and quantitative research methods. That allowed for a more comprehensive understanding of the research problem.

1.5 Scientific Questions

In an effort to enhance understanding of AR/VR banking app, this dissertation endeavors to examine scientific questions.

Nº	Question	Description
1	What are the technical challenges in integrating AR/VR with existing banking apps?	This question is to identify and address technical hurdles in the implementation of AR and VR.
2	What are the market trends and consumer preferences regarding AR/VR in banking?	This question is to understand the current market trends and consumer expectations in the context of AR/VR banking.
3	How do metaverse concepts integrate with AR/VR in enhancing digital banking?	This question is to explore the intersection of metaverse, AR, and VR in innovating digital banking experiences.

Table 1.1: Questions Table

This scientific investigations serve as a compass for this undertaking, guiding it toward innovative insights in the domain of AR/VR banking app.

1.6 Structure

The document has the following structure:

- Introduction – chapter giving a brief description of the project
- State of the Art – chapter divided into 9 main points:
 1. Trends in Digital Banking Transformation – Highlighting the main trends, consumer adoption rates and the impact of technological advances.
 2. Augmented Reality (AR) – Here we will explore what it is and how this technology overlays the real world with digital information, creating mixed experiences. It will be discussed how this technology can enhance the mobile banking experience.
 3. Virtual Reality (VR) – Examine what it is and how this technology has transformed various industries and user experiences. It will also address how VR can be applied in the context of financial institutions to create immersive experiences.
 4. VisionOS – Here we try to understand VisionOS, its computer vision techniques, performance metrics and ethical implications.
 5. Comparative Analysis of Augmented and Virtual Reality Tools – This chapter will explore the key features, user interfaces, and applications of each tool. By comparing Microsoft HoloLens, Oculus Rift, and Magic Leap.
 6. Comparative Analysis of AR/VR Devices – This chapter provides a detailed comparison of leading AR/VR devices like Apple Vision Pro, Microsoft HoloLens 2, Meta Quest 3, and Magic Leap 2, focusing on their key features, use cases, and applications in enterprise and consumer markets.
 7. AR/VR in the Financial Sector – This chapter examines how financial institutions are integrating AR/VR technologies.
 8. Benefits and Limitations of visionOS in AR/VR – This chapter explores the strengths and weaknesses of Apple's visionOS.
- Case Study – Will examine the innovative concept of **Spatial Banking**, focusing on how MR technologies, like Apple Vision Pro, and AI are transforming user experiences in banking. This case study will explore the potential for creating interactive, three-dimensional financial environments that enhance user engagement, improve decision-making, and offer personalized banking services.
- Development Process and Implementation – this chapter will cover the architecture used, the challenges faced, limitations encountered, and the solutions implemented throughout the development process.

1.7 Work Methodology

The work methodology for the development of this project was structured around the Scrum framework, utilizing two-week sprints to organize and manage the work efficiently. The sprint would have four different phases:

- **Sprint Planning** – At the start of each sprint, a sprint planning session was conducted to define the objectives and tasks for the upcoming two weeks. This involved breaking down product backlog items into smaller, manageable tasks. This process made estimation more accurate and allowed the team to prioritize tasks effectively, ensuring a clear direction and focus for the sprint ahead.

- **Daily Meetings** – Every day, a brief meeting, typically lasting around 15 minutes, is held to review progress on the previous day’s work and address any potential challenges. This meeting allows team members to provide updates, identify obstacles, and ensure that everyone is aligned for the day ahead.
- **Sprint Review** – At the conclusion of each sprint, a sprint review session took place to present the completed work. These meetings also provided an opportunity for the team to brainstorm, discuss potential new directions for the project, assign new tasks or features, and decide if any existing ones should be adjusted or removed.
- **Demo** – At the end of each sprint, a demonstration was conducted involving all members of the company, including the tech leads. These sessions provided a comprehensive overview of the project’s progress, showcasing the latest developments. Feedback was actively gathered during these demonstrations, which helped refine the product and ensure alignment with the expectations.

1.8 Ethical Considerations

This document was prepared with careful attention to ethical considerations.

- **Confidentiality and Review Process** – No details in this document were disclosed without the prior review of a company representative. To safeguard client confidentiality, all tests were conducted on a demonstration platform, with no actual client data or systems being involved.
- **Artificial Intelligence Usage** – Some parts of this thesis have been rephrased with the help of artificial intelligence tools. These tools were used carefully to maintain the accuracy of the content, ensuring that no sensitive or confidential information was included in the rephrased text. This approach adheres to academic standards of integrity and transparency, with proper acknowledgment given to original sources where applicable.

Chapter 2

State of the Art

The goal of this chapter is to establish a comprehensive framework for comprehending the project. It begins by presenting trends in the financial sector and mobile banking. It then delves into Augmented and Virtual Reality, emphasizing their benefits and potential applications within the financial industry. Following that, it provides an in-depth discussion about VisionOS, elucidating its nature and functionality.

2.1 Trends in Digital Banking Transformation

Digital banking transformation refers to the adoption of digital technologies by banks and financial institutions to enhance efficiency, customer experience, and introduce new services. This transformation is constantly evolving, driven by various technological trends and shifts in consumer expectations.

Digital banking transformation has significantly evolved over recent years. Initially, it was mostly about digitizing existing processes and introducing online and mobile banking services. Over time, this transformation has expanded to include a broader range of technologies and innovations. Banks began adopting more advanced solutions like Artificial Intelligence (AI), Machine Learning (ML), blockchain, and cloud computing to improve operational efficiency and offer more personalized customer experiences (Reynaldo C. Lugtu 2024) (Thompsett 2023).

In the article by (AB 2023) states that one of digital banking trends that are thriving even in 2024 is the **Customer Experience and Personalization** building an emotional connection with customers is becoming increasingly important. Digital banking platforms are focusing on personalized experiences and emotional engagement, similar to the approaches used by e-commerce platforms. Also (Marous 2022) states that there's a continuous increase in consumer use and expectations around digital banking, particularly mobile banking. Financial institutions are increasingly developing mobile-first strategies and services optimized for mobile users, such as mobile payments and check deposits.

Digital banking focuses on improving the customer experience, offering personalized services through AI-driven chatbots, tailored product recommendations, and intuitive user interfaces (Greenberg 2023). The focus on improving customer experience is integral to digital banking transformation. This involves not just understanding customer preferences (Marous 2022) but also offering time-sensitive personalized product recommendations. These efforts aim to enhance customer engagement in a safe and secure digital environment. The improvement in the use of data, analytics, and AI, although not as high as expected, has seen significant progress, indicating a growing emphasis on enhancing customer experience.

AR and VR are being integrated into mobile banking for enhanced user experiences. This includes virtual branches for remote banking services, AR-powered financial education tools, and AR-based property visualization for real estate investments (Akhtar 2023). AR and VR are gradually making their way into the financial sector, offering innovative ways to interact with banking services. These technologies have the potential to significantly enhance User Experience (UX) by transcending the limitations of traditional banking interfaces (Trends 2023). AR and VR provide novel methods for visualizing complex financial data in a three-dimensional, interactive environment. This can aid finance professionals in understanding intricate data correlations and making more informed decisions (ServReality 2023).

2.1.1 Metaverse Banking VR/AR

The metaverse is a collective network of Three-Dimensional (3D) virtual spaces where users can interact with a computer-generated environment and other users. This concept is a blend of "meta" (meaning beyond) and "universe" stated by (Gregersen 2023). In this virtual universe, the metaverse extends the concept of the internet by offering an immersive, interactive, and continuous digital experience. It is not just a single virtual world, but rather an expansive network of interconnected spaces and environments. These spaces are designed to be immersive, offering users a sense of presence and agency that goes beyond traditional, screen-based internet experiences. The metaverse is expected to encompass activities beyond gaming, including immersive shopping, learning, traveling, and socializing. The pandemic has fueled the acceptance of virtual interactions, further integrating the metaverse into various sectors (August 2022).

The integration of Metaverse technology into the banking sector is a rapidly evolving area that combines Virtual Reality (VR) and Augmented Reality (AR) to enhance customer experiences and financial services. This integration is reshaping how banking services are offered, providing a more immersive, interactive, and personalized experience for users. Banks are leveraging this technology not only to improve customer engagement but also to tap into new revenue streams, increase operational efficiency, and improve access to financial services, especially for individuals and small to medium enterprises (Yuhan Ma 2023).

Banks are experimenting with metaverse platforms to offer a more immersive and interactive customer experience. This approach is expected to lead to better customer engagement and satisfaction. For instance, virtual branches in the metaverse can simulate the experience of visiting a physical branch, allowing customers to perform various banking transactions in a virtual space. This not only makes banking more accessible but also more engaging for customers (Yuhan Ma 2023) (Marous 2023). The use of metaverse technology in banking can lead to improved operational efficiency. Virtual branches could reduce the need for physical spaces, thereby saving on real estate costs. Additionally, virtual reality training programs for employees can enhance learning experiences, reduce training costs, and improve service quality (Marous 2023). Financial institutions are exploring various innovative services in the metaverse, . One of the examples, JP Morgan opened a virtual lounge in Decentraland, offering information about blockchain and other technology initiatives, BNP Paribas also launched a Virtual Reality app that allows customers to use VR in their banking transactions, including account opening. And there are other interesting examples related to virtual branches, transactions, customer data displayed in augmented reality, and also the usage of virtual reality for training staff. Other banks, like CaixaBank and its subsidiary Banco Português de Investimento (BPI), offer virtual experiences, including banking and contact services. These innovations position banks as leaders in the digital transformation

of financial services (Yuhan Ma 2023). Also ensuring that banking services in the metaverse are user-friendly, inclusive, and accessible is crucial. This involves creating interfaces that are easy to navigate and catering to users with different abilities. Additionally, as metaverse banking is a relatively new concept, educating users and improving digital literacy are essential for its successful adoption (Yuhan Ma 2023).

The article (ebankit 2023) discusses the emerging trend of the metaverse and its potential impact on the banking industry. It describes the metaverse as a virtual reality world where users interact much like in the real world, with everything being digital yet connected to reality. The article predicts that by 2026, a significant portion of people will spend time in the metaverse for various activities including work, shopping, and entertainment. The banking sector is expected to adapt to this new digital era, with possibilities like virtual branches and augmented reality solutions enhancing customer experiences. The article also touches on the rise of virtual land and goods, and how these aspects might reshape banking services and customer interactions.

2.1.2 Challenges in integrating AR/VR in Metaverse Banking

Integrating Augmented Reality (AR) and Virtual Reality (VR) into banking within the Metaverse presents several technical challenges.

One of the primary challenges stated by (Desai 2023) is gaining customer acceptance and encouraging the adoption of AR/VR in banking. Many customers may not be familiar with these technologies or understand their benefits, leading to initial reluctance. Banks need to educate customers about the advantages of AR/VR, such as enhanced self-service capabilities and personalized experiences, through awareness campaigns and interactive demonstrations. Incentives like exclusive discounts or rewards could also motivate customers to try these technologies. Compliance with existing regulations in the banking industry is a requirement when implementing AR/VR technologies. Ambiguity may arise due to the lack of clear guidelines or frameworks tailored specifically to AR/VR in banking. Challenges include data privacy, customer consent, transactional security, and accessibility. Active engagement with regulators and industry associations is necessary to shape regulatory frameworks and ensure compliance.

Significant costs are involved in implementing AR/VR, including hardware, software, infrastructure, no Aly Aly no upgrades, and employee training. Banks must conduct comprehensive cost-benefit analyses to assess the potential ROI and justify the expenses. Identifying specific use cases where AR/VR can add value is crucial. Designing user-friendly interfaces and intuitive interactions for AR/VR can be challenging. Banks should invest in user experience design expertise and conduct user testing to identify and alleviate pain points (Desai 2023).

2.2 Augmented Reality (AR)

AR is a rapidly evolving technology that overlays digital information onto the real world, creating an enhanced and interactive experience. It integrates visual, auditory, haptic, somatosensory, and olfactory elements to enrich real-world environments with computer-generated data. VR, which immerses users in a completely virtual environment, AR enhances the user's perception of reality by adding digital information to the real world. An AR-enabled device with a camera (e.g. smart glasses, a tablet, or a smartphone) dissects a video feed to identify a physical object or the environment of a user. The augmented

reality device downloads information about the object from the cloud and superimposes digital information over it. The user can interact with the object or environment by sending commands to the cloud via touchscreen, voice, or gestures (Wacker 2023).

AR can significantly enhance learning and comprehension in the workplace. It is utilized for employee training, performance support, learning modules, new hire onboarding, and on-demand training opportunities. This technology is particularly beneficial in sectors like retail, manufacturing, healthcare, the military, and the automobile industry. It offers hands-on experience and guidance in critical professional skills (Microsoft 2023).

In the financial sector, there's a growing need to not only gather but effectively use large volumes of data. AR assists in data visualization, making complex data more accessible and understandable. This helps in better decision-making and strategizing in finance-related activities (Haritonova 2023). AR is being used to educate both employees and customers of financial institutions. By providing interactive and immersive experiences, AR makes understanding complex financial concepts and systems more engaging and effective (Nawijn 2018) (Mathew 2023). Also the article (Mathew 2021) states that financial institutions are utilizing AR to enhance customer experiences. For example, AR apps help users locate nearby banks and ATMs or even get detailed information about properties for real estate purposes. This improves the overall service experience for customers.

The author (BABA 2023) states that AR significantly enhances trading platforms and investment decision-making processes. For traders and investors, AR offers an immersive experience by providing real-time market data and portfolio management tools in an intuitive and engaging manner. One of the key advantages of using AR in trading is the ability to overlay real-time stock information onto the physical world, giving investors a comprehensive view of the market. This technology also enables financial analysts to create interactive 3D representations of data, aiding in better understanding market trends, correlations, and forecasting. For instance, AR-assisted stock market analysis tools can provide a more immersive perspective of market movements, allowing for more informed investment decisions. Moreover, AR facilitates collaboration in trading rooms by enabling remote teams to interact within a shared AR environment, streamlining communication and decision-making processes. Virtual site visits, enhanced through AR, provide investors with a thorough understanding of potential investments without the need for physical site visits, thus aiding in efficient due diligence.

AR offers innovative solutions for improving financial literacy, making it an invaluable tool for personal finance education. By using AR applications, users can receive real-time information and interactive visualizations that help them understand complex financial concepts in a more intuitive way. For example, AR can provide personalized guidance in areas such as budgeting, investment simulations, and virtual financial advisors. This empowers individuals to make more informed financial decisions (Mathew 2021).

2.3 Virtual Reality (VR)

VR is a technology that allows users to interact with a simulated environment, typically different from the real world. This technology uses computer modeling and simulation to create a three-dimensional visual or other sensory environment. Users interact with this artificial world through devices like headsets, goggles, gloves, or body suits, which are equipped with interactive devices and motion sensors. These sensors respond to the user's movements,

changing the view on the screen in real time and creating a sense of presence in the virtual environment (Britannica 2024). Beyond entertainment and gaming, VR has been applied in various industries, such as healthcare, education, architecture, engineering, and training simulations. In healthcare, VR is used for medical training simulations, while in architecture, it enables virtual tours of building designs. The versatility of VR demonstrates its ability to create experiences that are both realistic and imaginative, providing an immersive and interactive way of engaging with digital content (Fitz-Patrick 2023). The article (GCFLearnFree 2023) informs that VR market has expanded with major players like Oculus, HTC Vive, Sony PlayStation VR, and Valve Index offering various hardware options to cater to different user needs. These developments have made VR more accessible and versatile, revolutionizing the way various industries operate and deliver experiences. However, creating successful VR experiences requires a focus on user-centered design, intuitive interactions, user comfort, and emotional connections.



Figure 2.1: Virtual Reality. From (bluedot 2023)

One of the primary uses of AR and VR in finance is data visualization. Tools like D6 VR, developed by former Morgan Stanley investment analyst Andy Maggio, enable financial institutions to visualize their data in a three-dimensional and interactive environment. This technology revolutionizes how companies assess their reporting insights, allowing financial professionals to engage more intuitively with complex data sets and financial models. For example, Fidelity Labs has developed StockCity, a simulation of the stock market accessible through Oculus Rift, providing an immersive experience of financial data visualization (Group 2021), also states that AR and VR are enhancing customer service in the finance sector by offering virtual assistance and interactive data modules. Financial institutions are using these technologies to provide services like locating ATMs and offering virtual customer assistance. This has been particularly valuable during periods of restricted physical access, like the COVID-19 pandemic, allowing customers to receive financial services without leaving their homes. In terms of security, AR and VR are contributing to the development of more secure login procedures. Biometric scans, such as facial or iris recognition, are being used in conjunction with VR for secure access to digital banking services. This approach offers a

seamless and secure customer experience while safeguarding sensitive financial data (Group 2021)

2.4 VisionOS

VisionOS, developed by Apple, is an advanced operating system designed for spatial computing, specifically for the Apple Vision Pro. This OS represents a significant leap in immersive technology, integrating the digital and physical worlds in a seamless manner. It is built with inclusive design, supporting interaction through eyes, voice, or a combination of both. Pointer Control allows users to select alternative pointers like the index finger, wrist, or head, ensuring accessibility for a diverse range of users (Apple 2023d). It is seen as part of Apple's vision for the future of computing, where digital content is not just limited to screens but becomes an integral part of our physical environment. It aims to create a more immersive and interactive computing experience, redefining how we interact with technology on a day-to-day basis (Goodwin 2023).



Figure 2.2: Apple Vision Pro. From: (MacRumors 2024)

2.4.1 Design

Unlike traditional Two-Dimensional (2D) user interfaces, VisionOS offers a fully three-dimensional experience. This design approach transforms the familiar concept of a Home Screen into a more expansive, immersive 3D space, enhancing user interaction with digital content (Goodwin 2023). Also one of the standout features of VisionOS's design is its dynamic response to natural light and shadows. This means that the interface adjusts in

real-time to changes in lighting conditions, creating a sense of depth and realism that enhances the user's perception of distance and scale in the virtual environment (MacRumors 2023).

Cameras capture the room around the user and pass that through to the internal displays. With the headset on, the user is able to see a perfect representation of the room around them with the proper field of view and depth. Objects and windows appear to have a physical presence with placement anchors, shadows, and transparency. ARKit plays a part in developing experiences, but 3D scenes have to be built with SwiftUI and RealityKit (Insider 2024a).

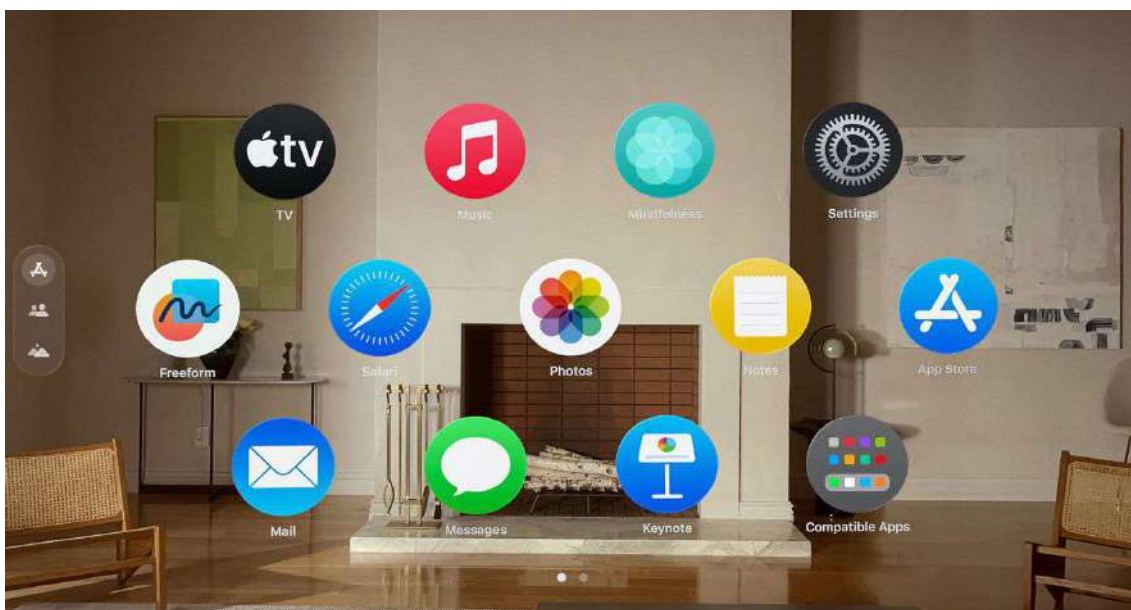


Figure 2.3: VisionOS Design.From:(Insider 2024b)

Apps in VisionOS are designed to be placed and resized within the virtual space, offering users a unique way to interact with multiple applications simultaneously. This aspect of the design provides a novel approach to multitasking and spatial organization of digital content(Insider 2024a)

2.4.2 Gestures and control

VisionOS utilizes eye tracking for selecting and highlighting interface elements. Users can look at an app or feature to select it, much like using a cursor. This method of interaction is not only intuitive but also efficient, allowing for quick navigation through the interface. Hand gestures are used to interact with the selected elements. Users can perform gestures like tapping, swiping, or pinching in the air to open apps, scroll through pages, or manipulate objects in the virtual space. This approach provides a more immersive and hands-on experience, allowing users to engage with the 3D environment in a natural way (MacRumors 2023) (Insider 2024a).

Adding to the gesture-based controls, VisionOS also incorporates voice commands. This feature enables users to issue commands or input text through speech, enhancing the ease of use and accessibility of the system (MacRumors 2023).

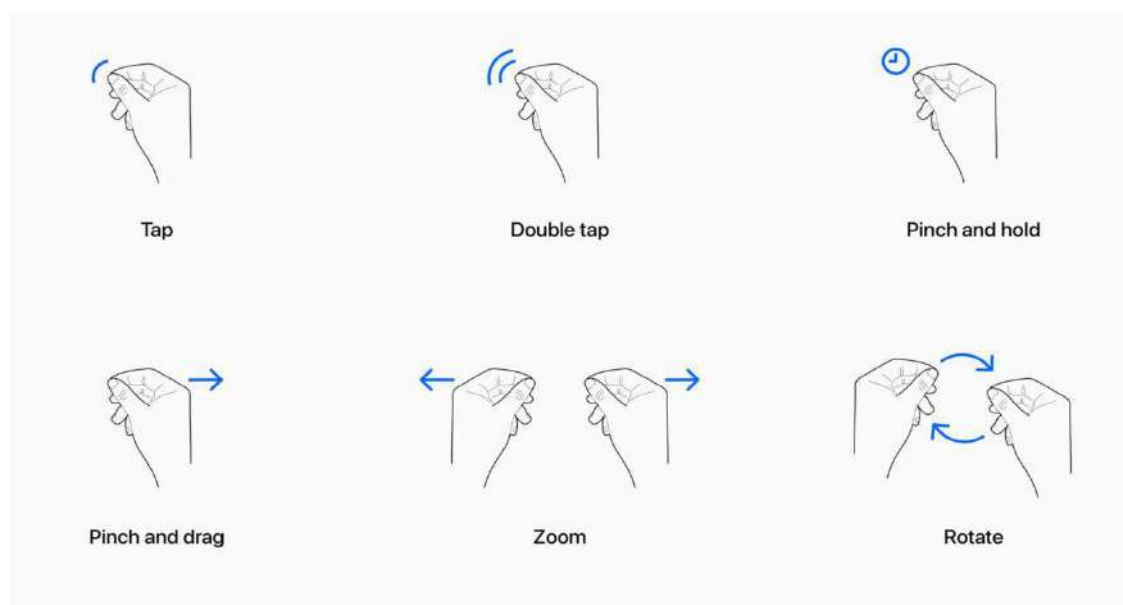


Figure 2.4: VisionOS Gestures and control. From: (Insider 2024b)

Pinching and dragging gestures are used for actions like scrolling and moving windows around. The system is designed to respond to the speed and direction of the gesture, allowing for a responsive and fluid interaction experience, supports zoom and rotate gestures, which are particularly useful in a 3D environment. These gestures allow users to manipulate virtual objects and interface elements in a way that is similar to physical interaction, providing a more engaging UX, VisionOS's control system is designed to allow users to interact with objects that are both near and far in the virtual space. This integration provides a more versatile and realistic interaction model, where users can reach out and use their fingertips to interact with elements directly in front of them or use more subtle gestures for distant objects (Insider 2024a).

Gesture	Description
Tap	Selecting items by tapping the thumb and index finger together, used for opening apps or interacting with digital elements.
Pinch and Drag	Moving or resizing objects by pinching the thumb and index finger together and dragging them to the desired location.
Pinch and Flick	Scrolling quickly by pinching the thumb and index finger, then flicking the wrist up or down for faster navigation through content.
Pinch to See More Options	Holding a pinch gesture to display additional options or settings for an object, similar to a right-click function.
Touch	Direct interaction with certain elements, such as typing on the virtual keyboard by touching the keys.

Table 2.1: Key Gestures in Apple Vision Pro. From (Inc. 2024)

2.4.3 FaceTime

FaceTime on VisionOS is expected to offer a more immersive experience compared to its implementation on other Apple platforms. The spatial computing capabilities of VisionOS could bring new dimensions to video calls, such as more engaging and interactive virtual environments. One of the innovative features of FaceTime in VisionOS is the ability to view life-size representations of call participants. This feature would leverage the 3D capabilities of VisionOS to create a more realistic and engaging communication experience, as if the participants are in the same room (MacRumors 2023).

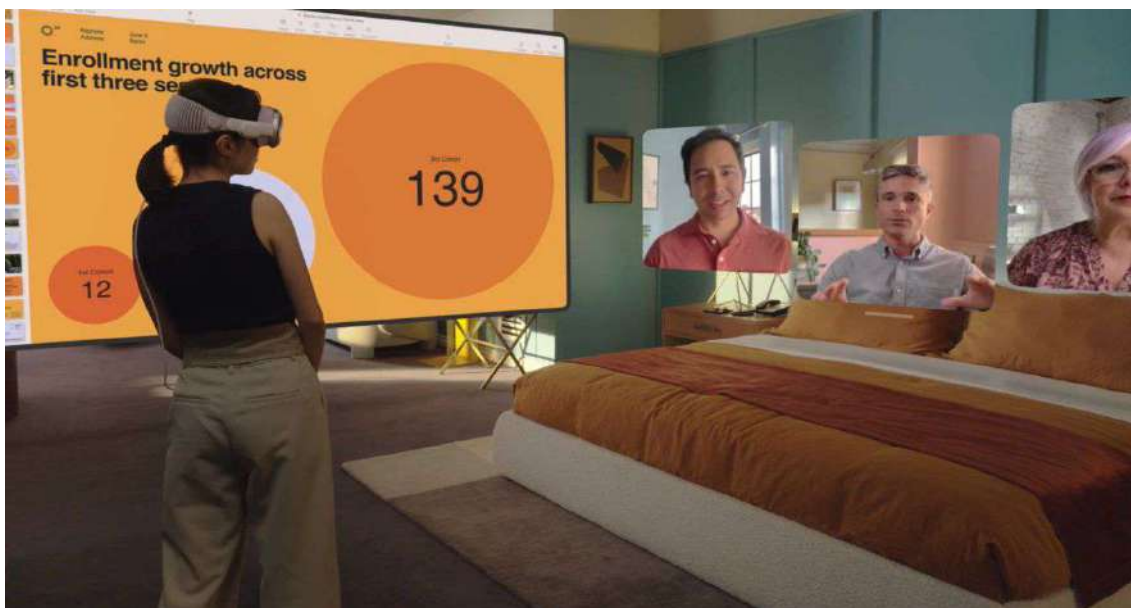


Figure 2.5: VisionOS Facetime. From: (Insider 2024b)

VisionOS introduces the concept of a 'Persona' in FaceTime. This digital representation reflects the user's face and hand movements in real-time, enhancing the expressiveness and realism of interactions during video calls. This feature would be particularly beneficial in a spatial computing environment, where body language and gestures play a significant role in communication (MacRumors 2023). The integration of FaceTime with other VisionOS apps could provide a seamless experience for users. For example, during a FaceTime call, users might be able to interact with 3D objects or share content from other apps in a collaborative manner, enhancing the overall utility and engagement of the service.

2.4.4 Security

VisionOS introduces Optic ID, a unique security feature using iris recognition for secure authentication. This technology encrypts the iris data and restricts access to it, ensuring it never leaves the device and is only accessible via the Secure Enclave processor. This level of biometric security demonstrates Apple's commitment to advanced and secure authentication methods (Beebom 2023).

In VisionOS, the data from cameras and sensors is processed at the system level. This design ensures that individual apps do not need direct access to the user's surroundings to provide spatial experiences, thus enhancing user privacy. By limiting the data available to third-party apps, VisionOS maintains a higher level of user privacy. An important aspect of VisionOS's privacy is the handling of eye input data. This data is not shared with Apple, third-party apps, or websites. Only the user's final selections, made by tapping fingers together, are transmitted. This approach to eye-tracking data is crucial for maintaining privacy, as it restricts the sharing of potentially sensitive eye movement information (Beebom 2023).



Figure 2.6: VisionOS Security.From:(Insider 2024b)

2.4.5 Development

Incorporates RealityKit and ARKit, Apple's advanced 3D rendering and augmented reality engines. These technologies provide realistic 3D content and animations, adapting to physical lighting and shadows. They offer capabilities like Scene Reconstruction and Skeletal Hand Tracking, enhancing the realism of digital content in the user's environment (Apple 2023d). The development is facilitated by Xcode, which supports the visionOS Software Development Kit (SDK). Tools like Reality Composer Pro and Unity are available for developers to create and test their applications and games, ensuring a robust development ecosystem (Apple 2023d) (Goodwin 2023). In VisionOS, apps can be placed anywhere in the virtual space and resized as needed. The "Environments" feature allows users to switch between their actual surroundings and virtual backdrops, like Mount Hood or other scenic locations, enhancing the immersive experience (MacRumors 2023).

The heart of VisionOS is Xcode, which is Apple's integrated development environment. It supports the VisionOS SDK, allowing developers to integrate advanced computer vision and augmented reality functionalities into their applications.

- **Xcode** – is Apple's IDE that now supports the VisionOS SDK. Developers can add a VisionOS target to their existing projects or create new apps, with the ability to iterate using Xcode Previews and a VisionOS simulator to test and adjust applications in different scenarios.
- **Swift** e **SwiftUI** – these are Apple's programming languages and frameworks that work in tandem with Xcode, offering a unified experience that takes advantage of Swift macros to simplify the development and design of apps, ensuring that they work seamlessly across multiple platforms and devices (Apple 2023e) (Apple 2023f).
- **ARKit** – An essential part of Apple's development ecosystem for creating augmented reality experiences that integrate with VisionOS, providing advanced AR capabilities directly in applications (Apple 2023a).
- **Reality Composer Pro** – is a sophisticated tool introduced by Apple to facilitate the creation of spatial content for visionOS apps, especially designed to work with the Apple Vision Pro headset. As an all-new tool that comes bundled with Xcode, Reality Composer Pro assists developers in importing, organizing, and optimizing 3D models, materials, and sounds for use in visionOS applications. Its integration with the Xcode build process allows for a seamless workflow in preparing assets for the unique spatial experiences that visionOS supports. This tool is a part of Apple's suite of development tools that aim to empower developers to create new types of apps that span a spectrum of immersion, taking full advantage of the spatial computing capabilities of Vision Pro (Apple 2023b).

The Unity Manual outlines visionOS as the operating system for Apple's Vision Pro and provides guidance for developers looking to build games or applications for visionOS. The manual covers the different modes in which apps can be displayed on visionOS, including Windows, Volumes, or Spaces, and gives an overview of the process for building Windowed Apps for visionOS using the Unity Editor (Unity 2024), also Unity's website provides resources for building spatial experiences for visionOS. It emphasizes the ability to quickly start developing for visionOS with thorough documentation, templates, and XR tools. Unity's cross-platform frameworks like AR Foundation and XR Interaction Toolkit are highlighted as key enablers to

bring existing mobile and XR apps to VisionOS without the need to rebuild core functionality (Unity 2023).

2.4.6 Spatial Computing Concepts

Apple's visionOS introduces unique concepts in spatial computing, which can be broadly categorized into three elements: windows, volumes, and spaces (Insider 2024a). The 2D apps are called "windows," the 3D objects are called "volumes," and full environments are called "spaces" in place of terms like AR objects or VR experiences.

- **Windows** – In visionOS, "windows" are similar to the traditional 2D app interfaces we see in macOS or iOS. These are essentially interfaces designed for spatial environments, enabling users to interact with 2D applications within a more immersive space. This concept is part of Apple's approach to integrate familiar user interface elements into the realm of spatial computing (Developer 2023).
- **Volumes** – Volumes in visionOS represent the 3D objects within the spatial computing platform. These are not restricted to traditional rectangular shapes and allow for more dynamic, three-dimensional content display. This aspect of visionOS is pivotal in creating more engaging and interactive experiences in a spatial computing environment (Developer 2023).
- **Spaces** – Spaces in visionOS denote the full, immersive environments. They offer the most comprehensive and immersive experiences within the visionOS architecture. This could encompass a wide range of applications, from virtual reality experiences to complex augmented reality interactions, representing the pinnacle of spatial computing in visionOS (Developer 2023).

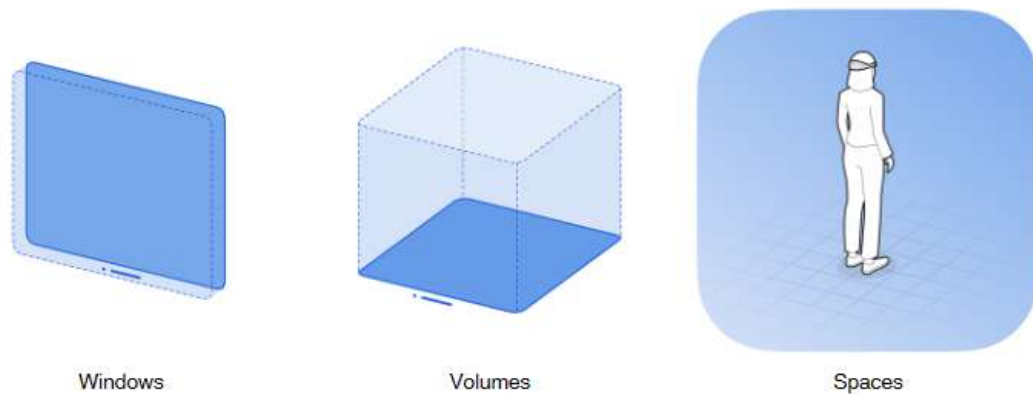


Figure 2.7: VisionOS Spatial Computing Concepts. From: (Insider 2024b)

Each of these elements: windows, volumes, and spaces, plays a critical role in the visionOS ecosystem. They enable a spectrum of experiences, ranging from simple 2D app interactions to fully immersive 3D environments, showcasing Apple's innovation in enhancing user experiences in spatial computing.

2.5 Comparative Analysis of Augmented and Virtual Reality Tools

In recent years, augmented reality (AR) and virtual reality (VR) technologies have rapidly advanced, transforming various industries. This chapter compares three leading AR/VR tools: Microsoft HoloLens, Oculus Rift, and Magic Leap.

The Microsoft HoloLens is a MR device that blends elements of AR and VR, allowing users to interact with digital content in real-world environments. It's widely used in sectors like healthcare, manufacturing, and education, providing interactive training and visualizing complex information. HoloLens is known for its advanced sensors, standalone operation, and integration with Microsoft's software ecosystem, making it a highly versatile tool for enterprise use.

The Meta Quest 3, developed by Meta (formerly Facebook), is a standalone VR headset designed primarily for gaming and entertainment, but it has also found applications in education, training, and collaborative workspaces. Quest 3 offers high-quality displays, Six Degrees of Freedom (6DoF) tracking, and hand-tracking capabilities, allowing users to interact naturally with virtual environments.

Magic Leap is an AR-focused device that competes directly with HoloLens in the enterprise sector. Like HoloLens, Magic Leap offers spatial computing and precise environmental understanding. Its focus on immersive experiences, hand and eye tracking, and lightfield technology makes it a powerful tool in healthcare, manufacturing, and design. Magic Leap is a standalone, enterprise-grade headset with its own set of sensors and computational capabilities, making it suitable for high-end, interactive applications.

This chapter will explore the key features, user interfaces, and applications of each tool. By comparing Microsoft HoloLens, Meta Quest 3, and Magic Leap, we will highlight their strengths and weaknesses. This comparison will help to understand which tool is best for specific needs and how these technologies can enhance productivity, learning, and engagement in various fields. The goal is to provide a clear and simple overview of these AR/VR tools and their potential to change how we interact with digital content.

2.5.1 Microsoft HoloLens

The Microsoft HoloLens represents a significant advancement in the integration of digital content with the physical world, offering a Mixed Reality (MR) experience that seamlessly blends augmented reality (AR) with the user's real environment. Introduced in 2016, the HoloLens was the first self-contained, holographic computer that allowed users to interact with high-definition holograms in their surroundings. Unlike traditional VR devices, which immerse users in entirely virtual worlds, the HoloLens overlays digital images, or holograms, onto the physical world (Microsoft 2024f).

The HoloLens operates as a standalone device, which is a key differentiator from other AR/VR devices that typically require a connection to a computer or smartphone. This autonomy is made possible by the device's onboard computing capabilities, including a custom-designed Holographic Processing Unit (HPU), a Central Processing Unit (CPU), and a Graphics Processing Unit (GPU). These components work together to process vast amounts of data from the HoloLens's array of sensors in real-time, providing a smooth and responsive mixed reality experience. This ability to function independently of other devices enhances the flexibility and mobility of the HoloLens, making it particularly valuable in professional environments where users need to move freely while interacting with digital content (Zhou 2018).

Environmental Understanding

Microsoft HoloLens employs advanced environmental understanding features that allow the device to perceive and interact with the physical world through its MR system. Using a combination of depth sensors, spatial mapping, and computer vision, HoloLens constructs a real-time 3D map of the user's environment. These capabilities allow the device to detect surfaces like walls, floors, and tables, enabling precise placement of digital objects in real-world spaces (Microsoft 2024d).

The core of the HoloLens's functionality is its ability to deliver a mixed reality experience, where digital objects are overlaid onto the real world, creating an environment where users can interact with both physical and virtual elements simultaneously. Mixed reality, as implemented by the HoloLens, allows users to see and interact with holograms as if they were part of their physical surroundings (Microsoft 2024f).

In addition to visual elements, the HoloLens also incorporates spatial sound that allows the HoloLens to emit sounds from specific locations in the environment, making it easier for users to identify the source of a sound and respond accordingly (Zhou 2018).

The Holographic Processing Unit (HPU) is a custom-designed chip that is central to the HoloLens's ability to deliver a real-time mixed reality experience. The HPU is responsible for processing the vast amounts of data generated by the device's sensors, including the depth cameras, Inertial Measurement (IMUs), and ambient light sensors (Microsoft 2024f).

Is also designed to be energy-efficient, which helps extend the battery life of the HoloLens. By offloading sensor processing from the CPU and GPU, the HPU reduces the overall power consumption of the device, allowing users to work for longer periods without needing to recharge (Microsoft 2024f).

- **Depth Cameras** – the HoloLens uses depth cameras to create a 3D map of the environment. These cameras work by emitting infrared light and measuring the time it takes for the light to bounce back from objects in the surroundings (Microsoft 2024f).
- **Inertial Measurement Units** – the IMUs in the HoloLens track the movement and orientation of the user's head. This data is crucial for maintaining the stability of holograms as the user moves around (Zhou 2018).
- **Ambient Light Sensors** – the ambient light sensors in the HoloLens detect the lighting conditions in the user's environment and adjust the brightness and contrast of the holograms accordingly. This ensures that holograms are always visible and legible, regardless of whether the user is in a brightly lit room or a dimly lit space (Microsoft 2024f).

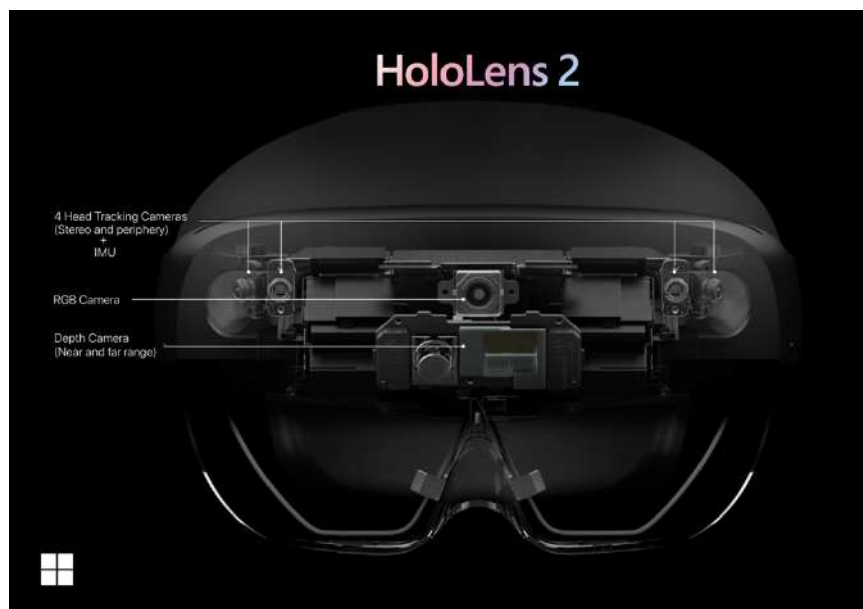


Figure 2.8: Microsoft HoloLens Hardware. From:(Microsoft 2024f)

User Experience and Accessibility

The user experience of Microsoft HoloLens is centered around ease of interaction and accessibility, making it usable for a wide range of professionals, from architects to medical

practitioners. The headset's ergonomic design ensures comfort during long sessions, with an adjustable fit system that allows users to wear it securely without causing strain or discomfort (Williams 2024b).

HoloLens features gesture-based controls through its hand-tracking system, allowing users to interact with virtual content intuitively. Gestures like the "air tap" enable users to select and manipulate digital objects, making the experience more natural and reducing the need for external controllers. Additionally, the voice command system, powered by Cortana, offers hands-free control, further enhancing accessibility for users who may have physical limitations or require multitasking capabilities (Jones and Davis 2023a).

The field of view (FOV) in HoloLens is optimized for mixed reality, ensuring that users have enough visual space to interact with virtual objects without overwhelming the peripheral vision. The integration of spatial audio further enhances the immersive experience, helping users locate and interact with virtual objects through sound cues. For instance, audio feedback adjusts dynamically depending on the user's position relative to the virtual object (Smith and P. Lee 2024).

Accessibility features include customizable interfaces, adjustable text sizes, and compatibility with assistive technologies, ensuring that users with varying needs can engage with the device. Microsoft has focused on making HoloLens adaptable for users with physical or cognitive disabilities, providing a wide array of customization options (Brown 2023).

Development and SDK

The Microsoft HoloLens SDK offers a robust environment for creating MR applications. The development ecosystem is centered around the `Microsoft.MixedReality.Toolkit`, a collection of tools and libraries aimed at simplifying the MR development process. The Mixed Reality Toolkit (MRTK) integrates directly with popular game engines like Unity and Unreal Engine, making it accessible to a wide range of developers, from beginners to experts (Microsoft 2024d).

The Microsoft HoloLens SDK provides several essential tools to streamline development and enhance productivity:

- **HoloLens Emulator** – the HoloLens Emulator allows developers to test MR applications in a virtual environment without needing physical hardware. It simulates HoloLens features like spatial mapping, hand tracking, and gesture recognition, making it invaluable for developers during the early stages of application creation (Microsoft 2024d).
- **Holographic Remoting** – this tool allows developers to download application rendering to a more powerful PC while streaming the output to the HoloLens device in real time (Williams 2024b).
- **MRTK** – is an open-source library designed to simplify MR development. It provides developers with pre-built components for common MR interactions such as spatial mapping, eye tracking, hand gestures, and input systems (Johnson 2024a).
- **Azure Spatial Anchors** – Azure Spatial Anchors is a cloud-based tool that enables the creation of persistent, cross-device spatial anchors. Developers can anchor virtual objects in physical space, and these anchors remain accessible across multiple sessions and devices. This capability is essential for multi-user MR experiences, as it allows users to interact with the same virtual objects from different locations, facilitating

collaboration in fields such as architecture, industrial training, and remote assistance (Jones and Davis 2023a).

- **Unity and Unreal Engine Plugins** – The HoloLens SDK includes plugins for Unity and Unreal Engine, two of the most popular development environments for MR applications. These plugins offer pre-configured components for spatial understanding, gesture inputs, and holographic rendering. Developers can quickly implement advanced MR features without needing to build systems from scratch (Brown 2023).

The HoloLens SDK supports **OpenXR**, an open standard for VR/AR development that allows for cross-platform application creation. OpenXR ensures that applications built for HoloLens can be ported to other mixed reality devices, such as the Oculus Quest or HTC Vive, without major modifications to the codebase (Brown 2023).

Its also support for voice command integration, powered by Microsoft's Cortana and other voice processing frameworks. Developers can easily implement voice commands to control the device or trigger specific actions within an application (Jones and Davis 2023a).

Gesture Recognition

One of the standout features of the HoloLens is its natural user interface, which allows users to interact with holograms using a combination of gestures, voice commands, and eye tracking. This intuitive interface makes the HoloLens easy to use and eliminates the need for external controllers, which can be cumbersome and limit the user's ability to interact with the environment.

- **Gestures** – The HoloLens supports a variety of hand gestures that allow users to interact with holograms in a natural and intuitive way.

Gesture Name	Description
Air Tap	Hold your hand out in a loose fist with the index finger pointing up, tap down your finger and quickly raise it back up. Used to select apps and holograms.
Air Tap and Hold	Start with an Air Tap but keep your finger down instead of raising it. Used to grab and move holograms or interact with menus.
Bloom Gesture (Start Gesture)	Hold out your hand with the palm facing you, and tap the Start icon that appears on your inner wrist. Opens the Start menu.
Hand Ray	Point your hand at a UI element to extend a "hand ray" from your palm, allowing you to select and interact with distant objects.
Scroll Gesture	Use a dragging motion with your fingers to scroll through content on holographic panels, such as webpages or documents.
Pinch to Zoom	Bring your thumb and index finger together to pinch, and move them apart to zoom in or closer to zoom out. Adjusts the size of holograms or zooms into content.
Two-Hand Manipulation	Use both hands to grab and manipulate larger holograms, allowing you to scale, rotate, or move them within your environment.
Voice Commands (Combined with Gestures)	Combine voice commands with gestures for more complex interactions, such as saying "Select" while performing the Air Tap gesture.

Table 2.2: HoloLens 2 Hand Gestures and Interactions. From (Microsoft 2024b)

- **Voice Commands** – In addition to gestures, the HoloLens supports voice commands, allowing users to control the device and interact with holograms using spoken instructions. This feature is powered by Microsoft’s Cortana voice assistant, which enables users to issue commands such as “select,” “open,” or “close” to interact with digital content. Voice commands are particularly useful in situations where the user’s hands are occupied or when precise control is needed without physical input. (Microsoft 2024e).
- **Eye Tracking** – The HoloLens also incorporates eye-tracking technology, which allows the device to follow the user’s gaze and adjust the position of holograms accordingly. Eye tracking can be used to enhance the accuracy of interactions, such as selecting a hologram by looking at it before performing a gesture (Microsoft 2024a).
- **Iris Recognition** – The HoloLens 2 employs iris recognition as its primary biometric authentication method. This technology is built on the Windows Hello framework, which uses a combination of hardware and software security features to securely process and store biometric data. The iris data is captured during the device’s setup process and is stored locally on the device in an encrypted format. This ensures that the

biometric data does not leave the device, thereby reducing the risk of unauthorized access or data breaches (Microsoft 2022).

Applications

- **Healthcare** – The HoloLens is used in the healthcare industry to improve surgical planning, medical training, and remote collaboration. Surgeons utilize it to overlay 3D models of a patient’s anatomy directly onto the body, enhancing precision during complex procedures like neurosurgery and orthopedics (Center 2023).
- **Manufacturing and Industry** – In manufacturing, HoloLens plays a crucial role in remote assistance, training, and quality control. It allows technicians to receive real-time guidance from experts who are not on-site, thereby reducing downtime and improving maintenance efficiency. The device is also used to train workers by overlaying digital instructions on machinery, enhancing learning outcomes and reducing errors (Microsoft 2024c).
- **Military and Defense** – The military uses HoloLens primarily through the U.S. Army’s Integrated Visual Augmentation System (IVAS). This system projects critical tactical information, such as 3D maps and thermal imagery, into soldiers’ field of vision, significantly improving situational awareness and mission effectiveness. The adoption of HoloLens in military operations marks a significant advancement in how soldiers plan, navigate, and execute missions, providing them with enhanced capabilities in various combat scenarios (Kipman 2021).

Industry Adoption and Real-World Applications

- **Airbus (Aerospace Industry)** – Airbus has integrated Microsoft HoloLens to accelerate the validation process for aircraft designs, significantly reducing the time required. Additionally, Airbus has deployed HoloLens across multiple stages of aircraft production to improve quality, safety, and efficiency. By leveraging mixed reality, Airbus has managed to cut manufacturing time by a third while improving overall product quality (Sokolowsky 2019).
- **Volkswagen (Automotive Industry)** – Volkswagen has been an early adopter of augmented reality and has used Microsoft HoloLens for including enhancing the user experience in their ID. family of electric cars. The company collaborated with Microsoft to develop a moving platform feature for HoloLens, allowing it to be used in vehicles for displaying navigational aids and other augmented reality interfaces. This technology helps improve driving safety and the overall customer experience by integrating real-time data with augmented reality (Bach 2022).
- **TD Bank Group (Banking and Finance)** – TD Bank has explored the use of augmented reality and HoloLens for enhancing customer service training and simulating customer interactions. This helps in providing employees with a more immersive learning experience, enabling better handling of real-world banking scenarios (Appinventiv 2023).
- **Allianz (Banking and Finance)** – In the insurance sector, Allianz has integrated AR technologies like HoloLens to streamline the claims process. This includes visualizing and assessing property damage in real-time, making the claims process faster and more accurate, which improves overall customer satisfaction (Avenga 2024).

Strengths and Weaknesses of Microsoft HoloLens

Strengths

- **Advanced Sensor Suite** – The HoloLens incorporates an array of sensors, including depth cameras, IMUs, and ambient light sensors, which provide a highly immersive mixed reality experience. These sensors enable precise tracking of the environment and user movements, allowing digital objects to interact naturally with the physical world (Center 2023).
- **Standalone Functionality** – Unlike many AR/VR devices that require connection to a PC or smartphone, HoloLens is a fully standalone device. This independence allows for greater mobility and ease of use, particularly in professional environments where users need to move freely (Microsoft 2024c).
- **Intuitive User Interface** – The HoloLens features a natural user interface that supports gestures, voice commands, and eye tracking. This makes it easy for users to interact with holograms without needing additional input devices, lowering the learning curve for new users (Microsoft 2024c).
- **Seamless Integration with Microsoft Products** – HoloLens integrates well with Microsoft's suite of products, including Azure, Dynamics 365, and Office 365. This makes it easier for enterprises already using these tools to adopt HoloLens into their workflows (Center 2023).

Weaknesses

- **Expensive for Large-Scale Deployment** – HoloLens incorporates cutting-edge technology, including high-resolution displays, multiple sensors, and a custom-built Holographic Processing Unit (HPU). These advanced components are not only expensive to develop but also costly to manufacture, contributing significantly to the overall price of the device (Haun 2024).
- **Limited Field of View** – Although HoloLens offers an immersive experience, its field of view is relatively narrow compared to some other AR devices. This limitation can sometimes detract from the overall user experience, as users might have to adjust their head movements to see the entire hologram or digital overlay ((Afifi-Sabet 2019).
- **Battery Limitations** – The Microsoft HoloLens 2 has notable limitations when it comes to battery life. According to reviews and technical evaluations, the device typically lasts between 2 to 3 hours of active use. This relatively short battery life is a limiting factor for professionals in industries such as manufacturing, healthcare, or field services, where extended periods of operation are often required.(Atwell 2024) (Sander 2023).

2.5.2 Meta Quest 3

The Meta Quest 3, released by Meta (formerly Facebook) in 2023, is a **VR** and **MR** headset designed to enhance both entertainment and professional applications. As the latest model in the Quest series, it builds upon the strengths of the previous versions by incorporating more advanced features, such as improved motion tracking and visual clarity, while adding significant mixed reality capabilities. Meta Quest 3 offers users the ability to interact with

both the digital and physical worlds simultaneously, making it a versatile tool for gaming, training, education, and remote work environments (Banker 2024).

Its standalone design allows it to function independently, without the need for a connected computer or external sensors. This portability, combined with a lightweight design, makes the Quest 3 particularly suitable for a wide range of users, from casual gamers to professionals in medicine, architecture, and education (Mobile 2023). With a focus on making immersive experiences accessible to a broader audience, Meta Quest 3 continues to push the boundaries of mixed reality technology, offering innovative solutions for both personal and enterprise use (Banker 2024).



Figure 2.9: Oculus Rift. From: (**OculusRiftS2024**)

Environmental Understanding

Meta Quest 3 employs inside-out tracking, a system in which cameras built into the headset scan the surrounding environment, allowing the device to track movement and interact with virtual objects without the need for external hardware. This makes the setup process straightforward and portable, and allows for more flexibility when transitioning between different physical spaces (Group 2023)

It supports **6DoF**, which tracks both the position and orientation of the headset and its controllers. This system ensures that movements are accurately reflected in the virtual or mixed reality environment, allowing for greater interaction with digital objects. Motion tracking is crucial for maintaining immersion in activities such as gaming or training simulations, where realistic movement can significantly enhance the user experience (Banker 2024)

A key feature of Meta Quest 3 is its ability to perform hand tracking, allowing users to interact with virtual objects without the need for controllers. The hand tracking system relies on the built-in cameras to detect hand movements, enabling gestures such as pinching, grabbing, and pointing to interact with the virtual world. This feature is essential for making interactions more natural and intuitive, especially in collaborative environments where hands-free operation can streamline workflows (Mobile 2023)

User Experience and Accessibility

Meta Quest 3 places significant emphasis on user experience (UX) and accessibility, aiming to make the device approachable for a wide audience, from casual gamers to professionals.

The Quest 3 is designed to be easy to set up and use, with an intuitive interface and support for hands-free navigation using the built-in hand-tracking capabilities. This removes the need for complex hardware setups, allowing for seamless transitions between virtual and physical environments (Group 2023; Mobile 2023)

The Meta Quest 3 is designed to work without external hardware like a PC, providing an untethered VR experience. The device includes a user-friendly interface, which is navigated through hand gestures, voice commands, or the optional controllers. Meta has also integrated several accessibility features into the Quest 3, making it more inclusive. These features include:

- **Text-to-speech functionality** – for users with visual impairments.
- **Hand-tracking** – for users who may have difficulty using traditional controllers.
- **Adjustable height settings** – within the virtual environment, allowing users in wheelchairs or with mobility impairments to interact with virtual objects without difficulty.

Development and SDK

The Meta Quest 3 SDK offers developers an extensive platform for creating applications in both VR and MR. Meta provides its Oculus SDK for developers, which includes support for Unity and Unreal Engine, making it easier to build immersive experiences across various sectors. The SDK includes libraries and tools that allow developers to incorporate hand tracking, spatial mapping, motion tracking, and environmental interactions into their applications.

One of the key strengths of the Meta Quest 3 SDK is its support for cross-platform development. Developers can create applications that work on both mobile and PC VR setups, allowing for flexibility in deployment. Additionally, the Quest platform offers Cloud Save API, enabling seamless backup of user data, ensuring that progress and settings are preserved across devices (Group 2023).

Meta Quest 3 supports the following major development environments and tools:

- **Unity** – The Meta Quest SDK is fully integrated with Unity's XR Interaction Toolkit, which allows developers to build VR/AR applications using pre-built components for motion tracking, spatial computing, and hand interactions (Technologies 2024).
- **Unreal Engine** – It provides powerful rendering capabilities and is ideal for creating highly realistic VR environments (Meta 2023).
- **Blender** – can be integrated into Meta Quest 3 workflows for 3D modeling and design. Developers can create high-fidelity 3D models and import them into Unity or Unreal Engine to build immersive, interactive experiences (Google 2020).
- **Oculus Developer Hub** – a tool designed to streamline the development process. It provides developers with tools to debug their applications, track performance, and run profiling tests to ensure applications run smoothly on the Quest 3's hardware (Meta 2023).
- **Meta's Cloud Anchors** – Meta's Cloud Anchor API allows multiple users to share the same virtual experience in real-time (Meta 2023).

Gesture Recognition

Gesture recognition in the Meta Quest 3 allows natural interaction with virtual environments through hand movements rather than controllers, enhancing immersion in gaming, professional training, and enterprise applications. The system utilizes a Hand Tracking API that maps gestures like pinching, grabbing, and pointing into virtual commands by tracking hand movements with built-in cameras and sensors. These inputs are processed to ensure seamless control within the virtual space. Additionally, the cameras use depth-sensing and computer vision algorithms to detect the hands' position and orientation in real-time, enabling accurate gesture interpretation even in complex environments (Meta 2023; Technologies 2024).

Common gestures recognized by the Meta Quest 3:

Gesture	Description
Pinch	Allows users to select or manipulate virtual objects by bringing their thumb and index finger together. Used commonly in 3D modeling and design applications.
Grab-and-Move	Enables users to grab virtual objects and move them within the environment. Frequently used in professional training and medical simulations.
Swipe	A gesture for navigating virtual menus or scrolling through virtual content by swiping the hand in a specific direction. Often used in enterprise applications.
Release	Allows users to drop virtual objects by opening their hand. Used in scenarios where objects need to be placed or released, such as in design or simulation tasks.

Table 2.3: Common Gestures in Meta Quest. From (Meta 2023; Technologies 2024)

Applications

- **Gaming and Entertainment** – Gaming continues to be a major focus for Meta Quest 3, with a wide library of VR games and access to social platforms like Horizon Worlds, which allow users to explore virtual spaces and attend events in VR environments. The untethered design offers more freedom of movement, making it easier to enjoy games without the restrictions of cables or external sensors (Banker 2024).
- **Education and Training** – In addition to its gaming capabilities, Meta Quest 3 is increasingly being adopted for educational purposes. Schools and universities are utilizing the headset to create interactive learning environments, where students can engage with virtual field trips, 3D models, or immersive simulations. This form of learning is particularly effective in fields like Science, technology, engineering, and mathematics (STEM), where students can explore concepts in a hands-on, visual manner (Banker 2024).
- **Healthcare and Medical Training** – In the healthcare sector, Meta Quest 3 is being used for medical training and therapy. Medical students and professionals can

practice procedures in virtual environments, reducing the need for expensive training equipment and minimizing the risks associated with hands-on practice. Virtual reality therapy is also gaining popularity as a tool for treating mental health conditions like PTSD and anxiety (Banker 2024).

Industry Adoption and Real-World Applications

- **Johnson Johnson (Healthcare)** – has adopted VR through the Meta Quest 3 to provide surgical training and medical simulations. The headset allows medical professionals to practice surgical procedures in a controlled virtual environment, significantly reducing risks associated with real-world practice. Similarly, **Cedars-Sinai Medical Center** uses VR to treat patients with anxiety and PTSD through virtual therapy (Group 2023; Mobile 2023).
- **Ubisoft and EA (Gaming)** – are among the leading gaming companies that are utilizing Meta Quest 3 to create immersive VR games. These companies are pushing the boundaries of interactive storytelling, allowing players to engage in worlds that are both visually stunning and highly interactive. **Horizon Worlds**, developed by Meta, allows users to socialize, play games, and attend virtual events (**MaplesKeller2017**).
- **Stanford University (Education)** – is incorporating the Meta Quest 3 into its educational programs to create immersive learning experiences for students. By using VR, students can engage with 3D models in subjects like biology, history, and engineering, where they can conduct experiments and explore environments in ways that are not possible in traditional classrooms. (Mobile 2023).

Strengths and Weaknesses

Strengths

- **Affordability** – one of the main strengths of the Meta Quest 3 is its affordability compared to other enterprise-focused headsets like Magic Leap or HoloLens. This makes it accessible to a wider audience, from individual consumers to businesses looking for cost-effective VR solutions (Banker 2024).
- **Untethered Design** – The Quest 3 does not require external sensors or connection to a high-end PC, allowing users to move freely and use the device in any space, which is critical for portability and ease of use (Group 2023).
- **High-Resolution Display** – The Quest 3's improved display offers sharper visuals and a higher refresh rate, reducing motion sickness and enhancing overall user immersion, particularly in applications that demand detailed visuals like 3D modeling or virtual meetings (Group 2023).

Weaknesses

- **No Built-In Eye Tracking** – While the Quest 3 supports advanced hand tracking, it lacks eye-tracking functionality, which is becoming increasingly important for certain enterprise and healthcare applications. Eye tracking allows for more accurate interaction with virtual environments, particularly in industries where gaze-based interactions are critical (Banker 2024).

- **Battery Life** – The Quest 3's battery life is shorter compared to some competitors, limiting its usefulness in professional settings where extended usage is required ((Group 2023).
- **Limited Enterprise Applications** – Compared to devices like Microsoft HoloLens 2, which is specifically designed for enterprise use, the Quest 3 is more focused on gaming and entertainment. This limits its application in highly specialized industries like architecture or advanced manufacturing (Banker 2024; Group 2023).

2.5.3 Magic Leap

Magic Leap is a state-of-the-art spatial computing platform that integrates MR by blending AR and VR to provide users with immersive digital content in the physical world. Developed by Magic Leap, Inc., it is primarily used in enterprise and professional sectors, offering solutions in healthcare, manufacturing, education, and architecture. Magic Leap's innovation lies in its ability to place digital objects in real-world environments with precise depth sensing and real-time mapping, enabling users to engage naturally with virtual content (Jones and Davis 2023b).

Magic Leap leverages a range of cutting-edge technologies, including (six degrees of freedom) tracking, lightfield displays, hand and eye tracking, and advanced spatial audio. These features enable users to experience immersive environments with accurate depth perception and natural interaction. The device has undergone significant upgrades since its initial launch, and the latest versions offer improved performance and wider applicability in enterprise settings (Smith 2024).



Figure 2.10: Magic Leap Headset. From: (Leap 2023)

Environmental Understanding

Magic Leap's spatial computing system is one of the most advanced in the field, allowing the device to map and interact with physical spaces in real time. By using a combination of depth sensors, lidar, and cameras (Jones and Davis 2023b).

The motion tracking uses , which allows the system to track the user's movements in three-dimensional space with high precision. This motion-tracking system is essential for ensuring that virtual objects remain stable and accurate relative to the user's position (Smith 2024).

Magic Leap features advanced hand-tracking and eye-tracking technologies that enable users to interact with digital objects naturally. With hand tracking, users can reach out and grab, move, or manipulate virtual elements without the need for traditional controllers. This is made possible by sensors that detect hand gestures, translating them into actions within the digital space (Jones and Davis 2023b).

Also employs lightfield display technology, which creates highly realistic visuals by mimicking how light behaves in the real world. Unlike traditional displays, which project flat images, lightfield technology allows users to perceive depth, making virtual objects appear as if they are physically present in the real world (Smith 2024).

Magic Leap utilizes headpose tracking to understand the orientation and position of the user's head in real-time. This feature ensures that the virtual objects stay anchored in the user's environment as they move their head around, maintaining the spatial accuracy of the digital content (Brown 2024).

Supports voice commands, which provide users with a hands-free interaction option, allowing them to control the device and navigate virtual environments through speech. Voice recognition enables users to execute commands such as selecting, opening, or navigating through applications without manual input (Leap 2023).

Also supports Bluetooth-enabled devices, such as wireless keyboards, game pads, and mice, expanding its usability in both consumer and professional environments. These external peripherals can be paired with the device for tasks that require traditional input methods, such as typing or gaming (Smith 2024).

User Experience and Accessibility

Magic Leap is designed with an emphasis on user experience, incorporating several features that make the device accessible for a wide range of users. The system's hand-tracking and eye-tracking technologies allow for controller-free interactions, enabling users to interact with digital objects through natural gestures. This makes Magic Leap more intuitive to use, particularly in professional settings where users may need to manipulate 3D models or conduct surgical simulations (J. Lee and Han 2022).

The spatial audio system further enhances the user experience by providing 3D sound that adjusts based on the user's location and movement within the virtual environment. Additionally, the device's lightweight design and adjustable headgear make it comfortable for extended use, which is essential for industries that require long-duration interactions, such as medical training and industrial design (Smith 2024).

Despite these strengths, accessibility may still be a barrier for some users, particularly in industries where technical expertise is required to operate the device fully. While Magic Leap's interface is intuitive, its setup and deployment in enterprise environments can be complex, particularly when integrating with existing workflows and systems. The need for high-end hardware also limits accessibility for smaller enterprises and individual users, as the device remains relatively expensive compared to other AR/VR systems (Johnson 2024b).

Development and SDK

Magic Leap's development ecosystem is built around its comprehensive SDK, which integrates seamlessly with popular platforms like Unity and Unreal Engine. Developers can

leverage the Magic Leap 2 SDK to create mixed reality experiences using advanced features like spatial computing, gesture recognition, and eye tracking. The SDK provides extensive APIs for real-time interaction, environmental understanding, and object manipulation, making it highly versatile for various professional applications (Smith 2024).

Unity's Magic Leap 2 Development Course offers developers the tools to create immersive MR experiences using Unity's engine, guiding through setup, content development, and deployment of applications on the Magic Leap platform (Technologies 2024).

The Magic Leap SDK is designed to support cross-platform development, enabling developers to create applications that can be deployed across various mixed reality platforms. This feature simplifies the development process for teams that need to create applications for both Magic Leap and other MR devices, such as Microsoft HoloLens. Additionally, the SDK provides detailed documentation, sample projects, and a robust support community, making it accessible to both novice developers and experienced professionals (Smith 2024).

The Magic Leap 2 SDK provides developers with a comprehensive suite of tools to create mixed reality (MR) experiences. Here is a detailed overview of the main tools available:

- **Magic Leap Remote** – The Magic Leap Remote allows developers to test and iterate on their applications without needing a physical device (Technologies 2024).
- **Lumin Runtime** – The Lumin Runtime is the core runtime environment that powers Magic Leap experiences on the headset. It supports features like real-time spatial mapping, hand and gesture tracking, and 3D content rendering. The runtime ensures that applications run smoothly on the Magic Leap 2 device and handle essential mixed reality interactions, such as object placement and environmental understanding (Smith 2024).
- **Unity and Unreal Engine Plugins** – Magic Leap provides dedicated plugins for both Unity and Unreal Engine—two of the most widely used game engines in the world. These plugins come with pre-configured components for developing headpose tracking, hand tracking, and light estimation capabilities (Technologies 2024).
- **Magic Leap Toolkit** – The Magic Leap Toolkit is an open-source collection of tools designed to accelerate the development process. It includes pre-built UI components, interaction models, and example projects (Brown 2024).
- **Zero Iteration Workflow** – The Zero Iteration Workflow enables developers to see live updates on the Magic Leap device as they make changes in the code. This workflow eliminates the need for repeated building and deploying after every change (Smith 2024).

Gesture Recognition

Gesture recognition in Magic Leap is a fundamental aspect of its interaction model, enabling users to naturally engage with virtual objects without the need for external controllers. The device's sensors and cameras track real-time hand movements, allowing for a broad range of gestures to be recognized and executed within mixed reality environments. These gestures are crucial for professional applications, especially in fields like healthcare, engineering, and education, where hands-free and intuitive interaction is essential for precision and ease of use (Brown 2024).

Magic Leap's hand tracking allows users to interact with virtual objects using intuitive gestures. The system employs advanced sensors and computer vision to detect hand movements in real-time. Some key gestures include:

- **Pinch-to-Select** – The pinch gesture allows users to select or manipulate virtual objects by bringing their thumb and index finger together, simulating a grabbing motion. This gesture is frequently used in applications such as surgical simulations, where precision is key (Leap 2023).
- **Grab-and-Move** – Swiping in the air allows users to scroll through menus or move virtual objects across the screen. This gesture is often used in navigation interfaces and data visualization environments, where quick navigation is required (Leap 2023).
- **Swipe** – By using two fingers, users can rotate virtual objects, allowing for full 3D manipulation. This gesture is particularly important in architectural design and product development, where users need to examine objects from multiple angles (Leap 2023) (Johnson 2024b).
- **Rotate** – By using two fingers, users can rotate virtual objects, allowing for full 3D manipulation. This gesture is particularly important in architectural design and product development, where users need to examine objects from multiple angles (Leap 2023) (Williams 2024a).
- **Release** – Releasing an object can be done by opening the hand after grabbing, dropping it back into the virtual environment. This is critical for applications that involve object placement, such as interior design (Leap 2023).

Applications

- **Healthcare** – Magic Leap has found significant applications in the healthcare sector, particularly in surgical training and medical simulations. Surgeons and medical students use the device to visualize 3D models of human anatomy, practice surgical procedures, and simulate complex operations in a risk-free virtual environment (Johnson 2024b). Magic Leap also supports telemedicine and remote collaboration, allowing medical professionals in different locations to share and interact with the same virtual models in real time (Jones and Davis 2023b).
- **Retail and Design** – In the retail sector, Magic Leap is used for product visualization and virtual try-ons. Retailers like IKEA and Wayfair use the device to allow customers to place virtual furniture in their homes and view how products fit within their space before making a purchase (Williams 2024a).
- **Entertainment and Gaming** – In entertainment and gaming, Magic Leap has partnered with developers to create augmented reality (AR) games that leverage the device's spatial computing and motion-tracking features. Unlike traditional gaming consoles, Magic Leap allows players to interact with virtual characters and objects in the real world, creating a more immersive gaming experience. Interactive storytelling is also enhanced through Magic Leap's ability to anchor virtual characters and scenes within the player's physical environment (Smith 2024).

Industry Adoption and Real-World Applications

- Stryker and Brainlab (Healthcare) – have adopted Magic Leap for surgical planning, medical training, and patient education. Surgeons use Magic Leap to visualize 3D models of patient anatomy, enabling preoperative planning. This capability has improved both surgical outcomes and trainee learning processes by offering interactive, real-time visualization (Smith 2024).
- Volkswagen (Manufacturing and Industrial Design) – has integrated Magic Leap into its automotive design and prototyping processes. The platform enables teams to collaborate on virtual car models in real-time, significantly reducing the design iteration cycle. Engineers can visualize and manipulate 3D car models without needing physical prototypes, which cuts down on production costs and accelerates the overall design process (Jones and Davis 2023b).
- Wayfair and IKEA (Retail and E-Commerce) – Have incorporated Magic Leap for virtual product placement and consumer interaction. Customers can use the headset to place virtual furniture in their living spaces, providing a realistic sense of scale and fit before making a purchase (Brown 2024).
- Cisco (Enterprise Solutions and Collaboration) – use Magic Leap for remote collaboration and industrial training. The device enables teams located in different geographical locations to work together in a shared virtual environment (Brown 2024).

Strengths and Weaknesses

Strengths

- Advanced Hand and Eye Tracking – Magic Leap offers precise hand and eye-tracking technologies that allow for natural interaction with digital objects. These features are essential for applications requiring complex user interactions, such as surgical training and industrial design (Johnson 2024b).
- Spatial Computing Capabilities – The ability to understand and interact with physical environments in real-time through depth sensing and spatial mapping makes Magic Leap a powerful tool for industries requiring accurate placement of virtual objects in real-world settings (Brown 2024).
- Lightfield Technology – Magic Leap's use of lightfield displays enhances depth perception and reduces eye strain, providing a more immersive visual experience that is crucial for prolonged use in fields such as architecture and medical training (Smith 2024).
- Enterprise Focus – The device's focus on enterprise solutions provides highly specialized features that cater to professional sectors like telemedicine, 3D modeling, and remote collaboration (Johnson 2024b).

Weaknesses

- Cost – Magic Leap is expensive, making it less accessible for smaller businesses or individual consumers. Its high cost is a significant barrier to adoption in industries with limited budgets, particularly compared to alternatives like Microsoft HoloLens or Google ARCore (Brown 2024).

- **Limited Consumer Applications** – While Magic Leap excels in enterprise settings, it has limited applications in the consumer market. Most of its development has been geared toward professional use cases, which restricts its appeal for gaming or general entertainment (Smith 2024).
- **Smaller Developer Ecosystem** – The development community around Magic Leap is relatively small compared to larger platforms like ARKit or ARCore, which limits the availability of third-party applications and can slow down software development (Smith 2024).
- **Hardware Constraints** – Magic Leap’s reliance on powerful hardware components, such as its lightfield display and advanced sensors, increases its size and weight, which can cause discomfort during extended use. Additionally, the need for frequent updates and maintenance may limit its use in certain industries (Smith 2024).

2.6 Comparative Analysis of AR/VR Devices

Feature	Apple Vision Pro	Microsoft HoloLens 2	Meta Quest 3	Magic Leap 2
Device Type	Mixed Reality (MR)	Mixed Reality (MR)	Virtual Reality (VR)	Augmented Reality (AR)
Price	\$3,499 (expected 2024)	\$3,500 (Developer Edition), \$4,950 (Industrial)	\$499	\$3,299 (Enterprise)
Display	4K Micro-OLED, 120° FOV	2K per eye, 52° FOV	2064 x 2208 per eye, 100° FOV	1440x1760 per eye, 70° FOV
Processor	Apple M2 + R1	Qualcomm Snapdragon 850	Snapdragon XR2 Gen 2	AMD Zen 2 SoC
Input Methods	Hand, eye tracking, voice	Hand, eye tracking, voice	Hand tracking, 6DoF controllers	Hand, eye tracking, voice
Operating System	visionOS	Windows Holographic	Meta Quest OS	LuminOS
Battery Life	Up to 2 hours (external battery pack)	2-3 hours	2-3 hours	Up to 3 hours (with Compute Pack)
Special Features	Spatial audio, 3D video capture	Advanced hand tracking, spatial mapping	Mixed reality passthrough, standalone VR	Dynamic dimming, advanced optics
Use Cases	Consumer, enterprise, media streaming	Enterprise, healthcare, collaboration	Gaming, productivity, some enterprise use	Enterprise, healthcare, design

Table 2.4: Comparison of Apple Vision Pro, Microsoft HoloLens 2, Meta Quest 3, and Magic Leap 2. From (Compare 2024)

2.7 AR/VR in the Financial Sector: Current Adoption

Bank of America has been a leader in integrating **VR**, they use Oculus (Meta Quest) for employee training. Their program, launched in 2021, uses virtual reality simulations to train employees on customer service, conflict resolution, and handling complex financial

transactions. This VR platform allows employees to engage in realistic scenarios, improving both technical skills and emotional intelligence (America 2024).

Similarly, **BNP Paribas** has embraced VR technology by developing virtual reality banking branches. The project, launched in 2017, enables customers to access banking services remotely. Customers can explore banking services in a fully immersive virtual environment, such as managing accounts, making transactions, or exploring financial products like loans and investments (Paribas 2024).

Mastercard, in collaboration with various technology firms, is exploring AR/VR solutions for fraud detection and transaction security. They aim to create immersive environments where AI-driven AR/VR systems detect and prevent fraudulent activities in real-time. This includes creating spatial visualizations of financial transactions to enhance the understanding of potential threats and optimize security. Mastercard's long-term goal is to integrate these technologies with advanced biometric authentication methods for more secure financial transactions (Insights 2023).

2.8 Benefits and Limitations of visionOS in AR/VR

2.8.1 Benefits

- **Immersive Interaction with Spatial Computing** – visionOS offers precise eye-tracking, hand-tracking, and spatial awareness, providing an immersive AR/VR experience. This enhances user interaction by enabling natural gestures, voice commands, and gaze-based navigation, making it user-friendly for both professional and personal use (Inc. 2024; Mobile 2023).
- **Limited Consumer Applications** – visionOS is designed to handle various applications, including gaming, education, healthcare, and finance. The adaptability of the system to diverse industries, including financial services where sensitive data handling is critical, is a core benefit (Inc. 2024).
- **Seamless Integration with the Apple Ecosystem** – One of the significant strengths of visionOS is its deep integration with the Apple ecosystem. Devices such as iPhones, iPads, and Macs work smoothly with the Vision Pro headset, allowing for seamless data sharing, continuity, and access to a wide range of applications. This makes cross-platform usability intuitive for existing Apple users (Inc. 2024).

2.8.2 Limitations

- **High Cost** – One of the major limitations of Apple Vision Pro is its high cost, which makes it inaccessible to many consumers and smaller enterprises. (TechRadar 2024).
- **Battery Life** – One of the practical limitations of Apple Vision Pro is its battery life. High-performance features such as spatial computing, eye-tracking, and advanced graphics rendering consume significant power, limiting the headset's usability for extended sessions without frequent recharging (TechRadar 2024).

Chapter 3

Case Study

3.1 Case Study: User Experience Design in Spatial Banking for Apple Vision Pro with AI Integration

3.1.1 Introduction

Recent advances in MR and AI are transforming how people interact with digital services, including banking. The Apple Vision Pro, a new MR device, offers opportunities to change the way users manage their finances by combining 3D visuals with intelligent systems. By using spatial design and AI, banking can become more interactive and personalized, creating what is known as **spatial banking**.

This case study draws upon two primary sources: (UXDA 2024b), which delves into the technical and design aspects of UX in Apple Vision Pro, and (UXDA 2024a) from UXDA's website, which focuses on the integration of AI to enhance and personalize banking interactions.

The objective of this study is to examine the impact of mixed reality and AI technologies on UX design for the banking sector, highlighting the benefits, challenges, and practical implications for both users and financial institutions.

3.1.2 Defining Spatial Banking

Spatial banking refers to the application of banking services within a mixed reality environment, where users can interact with financial data and tools in 3D space. This approach represents a departure from the traditional 2D interfaces commonly used on smartphones and computers, allowing for a more immersive and intuitive experience. Spatial banking utilizes the depth, spatial perception, and enhanced interactivity of mixed reality devices like the Apple Vision Pro to present financial information in a more engaging way.

The (UXDA 2024b) outlines key principles for spatial banking UX design, emphasizing the importance of depth perception, natural spatial interactions, and seamless integration with real-world tasks. These principles aim to improve how users navigate and engage with financial data, making complex financial concepts easier to grasp by presenting them in a visual and interactive manner.

3.1.3 Key UX Design Principles

- **Depth Perception** – Leveraging the three-dimensional capabilities of the Apple Vision Pro, spatial banking allows users to perceive financial data in layers and depth, giving

a more intuitive understanding of the information. For example, charts, graphs, and financial metrics can be displayed as floating 3D objects, providing users with the ability to explore the data from different angles.

- **Natural Gestural Interactions** – In spatial banking, users can manipulate financial objects through natural gestures and movements. This form of interaction makes the experience more intuitive, as it mimics the way users interact with physical objects in the real world. Swiping, grabbing, and rotating financial models are examples of how gestures can simplify navigation through complex financial datasets.
- **Smaller Developer Ecosystem** – The development community around Magic Leap is relatively small compared to larger platforms like ARKit or ARCore, which limits the availability of third-party applications and can slow down software development (Smith 2024).
- **Seamless Integration with Physical Space** – The ability to integrate digital banking experiences with real-world environments is a critical feature of mixed reality banking. For instance, users can manage their finances while interacting with other virtual or physical objects without having to switch between devices or disrupt their workflow. This enhances multitasking and allows for a more fluid banking experience.

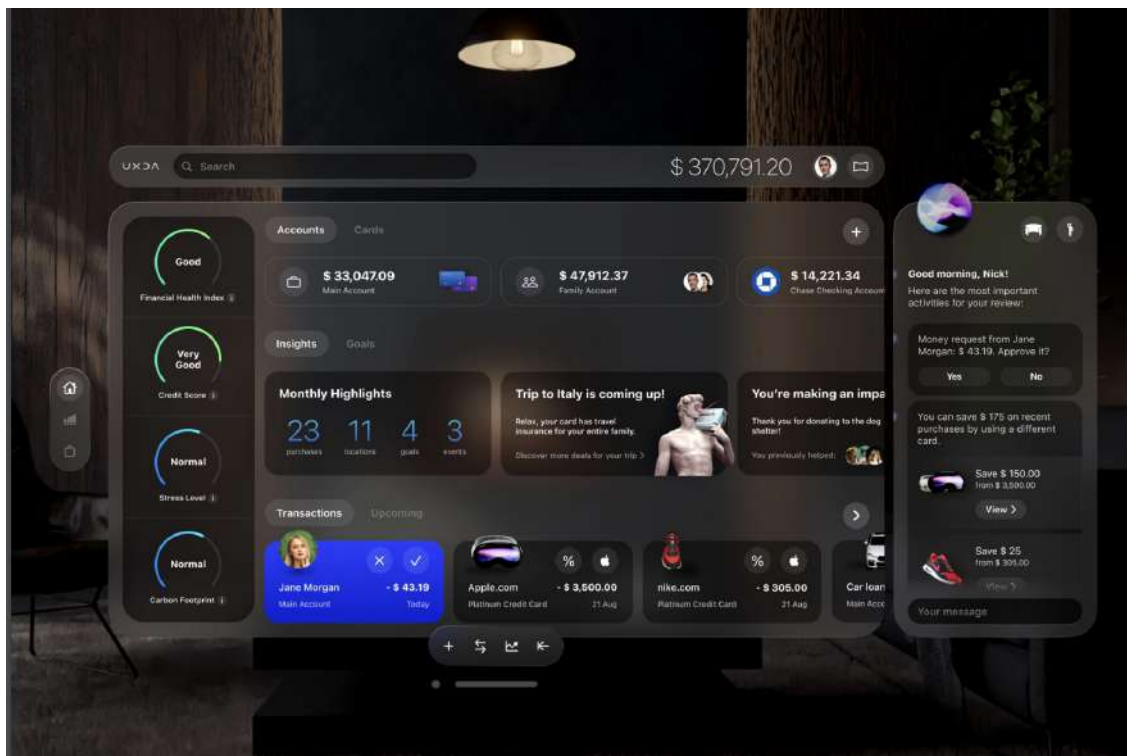


Figure 3.1: Snapshot dashboard. From: (UXDA 2024a)

3.1.4 Technological Capabilities of Apple Vision Pro

Apple Vision Pro is equipped with advanced technologies that make it suitable for spatial banking. These include high-resolution displays, which offer crisp, detailed visualizations of 3D objects, and precise sensors that track users' head movements, gaze, and hand gestures.

Additionally, spatial audio enhances immersion by providing directional sound cues that align with the visual elements of the interface.

The Apple Vision Pro also supports dynamic spatial rendering, allowing users to interact with virtual objects in their immediate environment. This enables users to position financial tools and data in their physical space, creating a personalized and flexible workspace for managing their finances.

The integration of Apple Vision Pro in banking offers several potential applications:

- **3D Financial Data Visualization** – Users can interact with 3D representations of their financial data, making it easier to understand complex information. For example, a 3D model of spending patterns or investment portfolios could be manipulated and explored in real-time, providing users with deeper insights into their financial health.
- **Virtual Financial Advisors** – AI-powered virtual advisors could appear within the mixed reality space, offering personalized financial advice based on the user's data. These advisors could guide users through financial decisions in a more engaging and interactive manner, simulating the presence of a financial expert in the room.
- **Customized Financial Environments** – Users can create and organize virtual financial spaces that reflect their preferences. This might include customizable dashboards that allow users to arrange financial tools and data points in ways that are most useful to them, enhancing both efficiency and personalization.

3.1.5 The Role of AI in improving Spatial Banking

The integration of AI is crucial for enhancing the spatial banking experience, as explored in the article (UXDA 2024a). AI plays several roles in improving personalization, decision-making, and user engagement:

- **Personalization** – AI can analyze user behavior and preferences to tailor the spatial banking environment. For example, it can dynamically adjust the layout of 3D financial dashboards based on a user's interaction patterns, ensuring that the most relevant information is always within reach.
- **Predictive Financial Insights** – AI-powered tools can offer predictive insights by analyzing historical financial data and market trends. These insights could be displayed in real-time as users interact with their financial environment, helping them make informed decisions regarding investments, savings, or expenditures.
- **Automated Assistance** – Through natural language processing (NLP), AI-powered assistants can interact with users via voice commands, providing instant responses to financial queries. This reduces the need for manual navigation through menus, creating a more fluid and user-friendly banking experience.

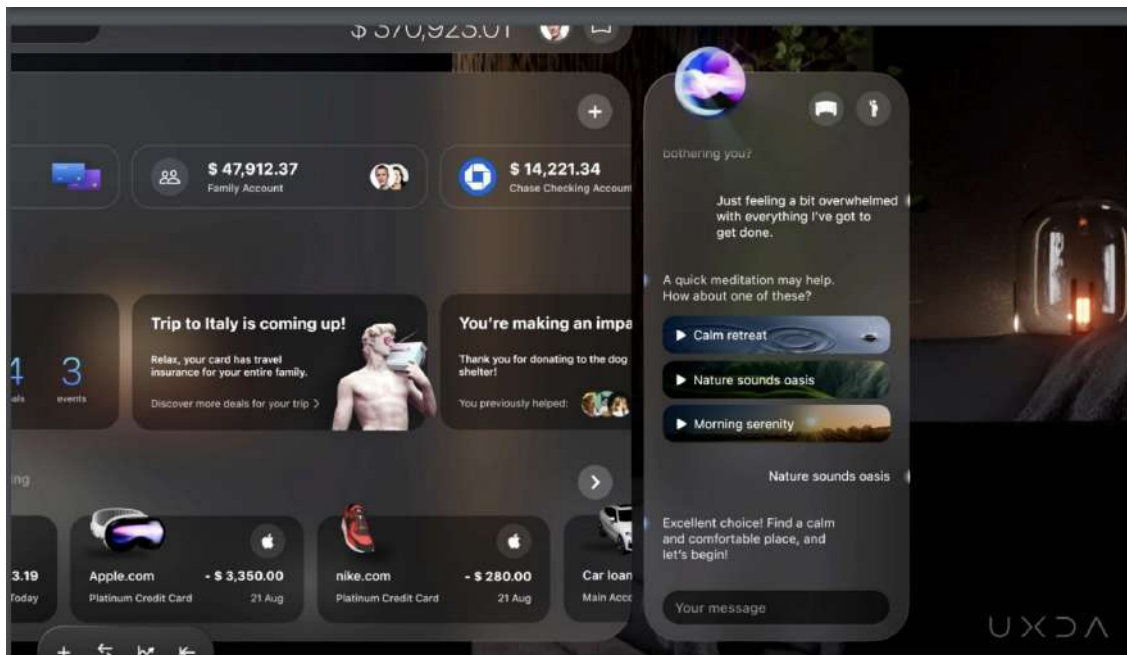


Figure 3.2: AI Advisor. From: (UXDA 2024a)

3.1.6 Benefits of Spatial Banking with AI

Benefits

- **Enhanced User Engagement** – The combination of mixed reality and AI results in a highly interactive and personalized experience, increasing user engagement. The ability to interact with financial data through 3D models and virtual assistants creates a more immersive and intuitive banking environment.
- **Improved Financial Literacy** – By presenting financial data in a visually engaging and interactive format, spatial banking can help users better understand complex financial concepts. AI's predictive insights further empower users by providing them with actionable information tailored to their specific financial goals.
- **Increased Accessibility** – AI integration allows for more inclusive banking experiences, as virtual assistants can cater to users with different levels of financial literacy and provide support in multiple languages.

3.1.7 Challenges Identified

Despite the advantages of AI-powered spatial banking, several challenges must be addressed for successful implementation.

Security and Privacy Concerns

Handling sensitive financial information in a mixed reality environment introduces new security and privacy risks. Unlike traditional systems where data is confined to secure, closed systems, MR environments project data into the user's physical space, which may increase the risk of unauthorized access or breaches.

- **Data Encryption** – Financial institutions must ensure that all data transmitted in the MR environment is encrypted end-to-end, protecting user privacy from potential cyber threats.
- **User Privacy in Public Spaces** – The projection of financial information into a user's physical environment also raises concerns about privacy when using the system in public spaces. Banks must consider mechanisms to prevent sensitive information from being visible to unintended third parties.

User Adoption and Learning Curve

One of the primary barriers to the adoption of spatial banking is the user learning curve. While younger users familiar with modern technology may adapt more quickly to the 3D interface and gesture-based controls, older or less tech-savvy users might struggle.

- **User Training and Support** – Banks will need to invest in user education and training to facilitate a smooth transition to this new technology. Comprehensive support, including tutorials and onboarding programs, will be crucial to ensure users are comfortable using spatial banking.
- **Cultural Shift** – Beyond the technical aspects, adopting spatial banking may require a broader cultural shift in how people manage their finances. Moving from 2D screens to immersive 3D environments represents a significant change in user behavior, requiring time and effort to become the new standard.

High Implementation Costs

Developing and maintaining spatial banking systems is capital-intensive, requiring significant investment in hardware (such as Apple Vision Pro devices) and the development of AI-driven MR software platforms. For many financial institutions, especially smaller banks or credit unions, the cost of adopting these technologies may be prohibitive.

- **Scalability** – The high costs associated with hardware and software development could limit the scalability of spatial banking solutions, particularly for institutions with limited financial resources. Finding cost-effective ways to implement these technologies will be essential for widespread adoption.

3.1.8 Conclusion

The findings of this case study demonstrate that spatial banking, powered by the Apple Vision Pro and AI integration, has the potential to revolutionize user experiences in the financial sector. By offering a more intuitive, engaging, and personalized interface, these technologies can transform how users interact with their financial data, improving decision-making and overall financial literacy.

However, several challenges must be addressed to ensure the success of spatial banking. These include mitigating security and privacy risks, overcoming the user learning curve, and addressing the high costs of implementation. As the technology evolves, financial institutions will need to carefully weigh the benefits and challenges to determine whether adopting spatial banking aligns with their strategic objectives.

Future research should focus on pilot studies within financial institutions to assess the practical viability of these technologies and to refine UX design principles for broader user acceptance. Additionally, further investigation into cost-effective security solutions and strategies for enhancing user adoption will be critical for long-term success.

Chapter 4

Development Process and Implementation

4.1 Summary

The development of the mobile banking application for VisionOS focused on creating an immersive version of the existing mobile app, utilizing AR and VR features. The primary goal was to retain the core functionality of the mobile app while modifying its interface and interaction model for the VisionOS platform.

Originally designed for touch-based interaction, the app was extended to support spatial gestures and voice commands, leveraging Apple's Vision Pro hardware. Interactions that were previously based on tapping and swiping on mobile devices were reimaged for gestures and voice input in VisionOS.

Maintaining compatibility with existing backend services, such as account management and transaction history, was crucial to ensure consistency between the mobile and VisionOS versions. The focus was on delivering a seamless user experience, preserving the integrity of the app's core services while adjusting the interface to suit the new spatial computing environment.

In summary, the development process involved creating a VisionOS version of the app that retains the same core services as the mobile version, with adjustments made to the interface and interaction methods to take advantage of VisionOS capabilities.

4.2 Architecture

The development of ebankIT's mobile banking application for VisionOS required adjustments to its technical architecture to support the new environment while ensuring that core functionalities from the mobile app were maintained. The new architecture was designed to leverage the immersive capabilities of VisionOS, such as gesture control and voice commands, while providing a consistent user experience similar to the mobile version.

During the process of building the VisionOS version, a key change involved the management of external libraries. In the mobile version, many libraries were integrated using CocoaPods. However, for the VisionOS version, it was necessary to switch to ****SPM****, as only certain external libraries, are currently available through ****SPM****. This adjustment ensured compatibility with VisionOS, as some libraries had not yet been adapted for use with CocoaPods in this environment.

Switching to **SPM** also made dependency management easier, integrating libraries directly into Xcode, simplifying the setup process and reducing the chance of conflicts during development.

4.2.1 Modular Design

The architecture followed a modular design, allowing different components of the application to be developed independently without requiring significant changes to the overall structure. While the mobile app remained intact, the VisionOS version was built separately with the same core functionalities but redesigned for a 3D spatial environment. This modular approach ensured that backend services, business logic, and security features were reused without modification, enabling both the mobile and VisionOS versions to share the same core services while adapting their user interfaces to the respective platforms.

4.2.2 Core Architecture and Infrastructure

At the core, the application’s backend remained unchanged, as the same services—account management, transaction history, and authentication continued to operate through existing APIs. This backend communicates with both the mobile and VisionOS versions, ensuring consistency across platforms. The use of RESTful APIs allows both versions of the app to access real-time banking services, ensuring that the data flow and processing logic are centralized and uniform.

The block diagram below provides a simplified graphical overview, illustrating how various components and domains interact through APIs, databases, and external services.

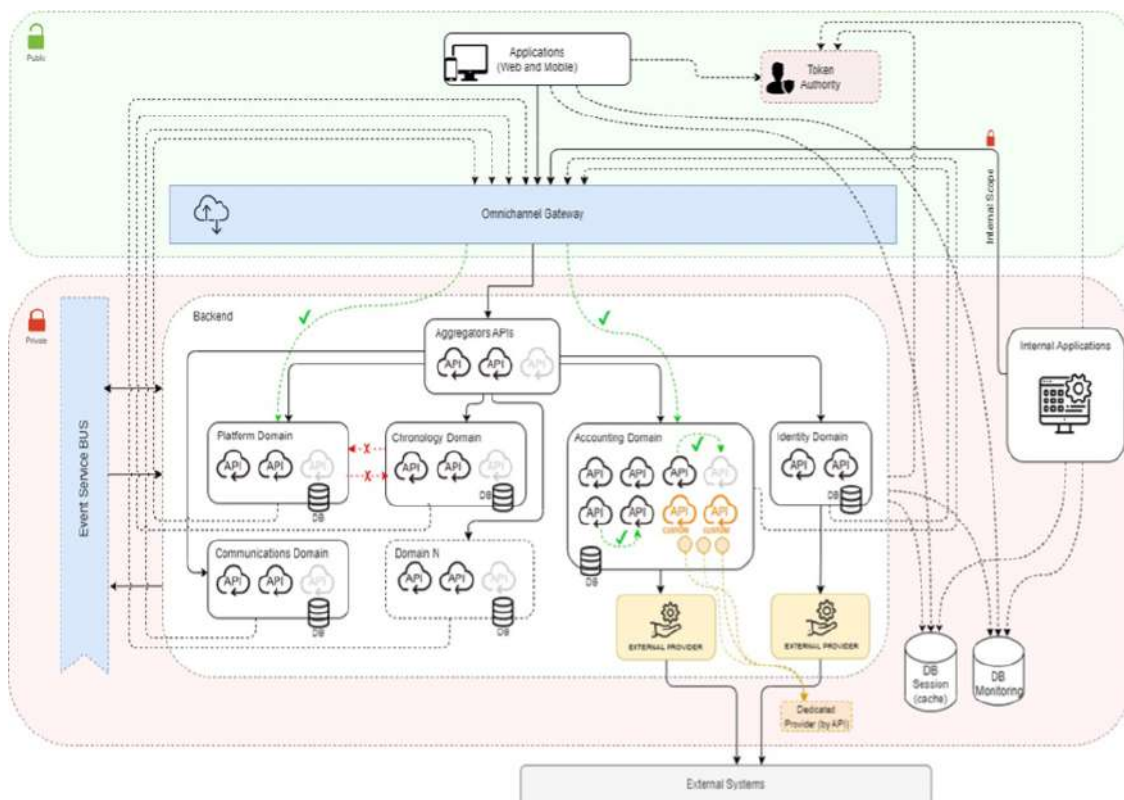


Figure 4.1: Block Diagram

The block diagram illustrates the core structure of a distributed system, highlighting how different components and domains interact with each other. Each layer plays a vital role in ensuring efficient communication, secure access, and scalable data processing across the system. Below is a simple breakdown of each layer's function:

- **Omnichannel Gateway** – manages communication between web and mobile applications and the backend.
- **Domain and API Aggregators** – each Domain (such as the Platform Domain, Accounting Domain, Identity Domain) is connected to APIs that handle specific functionality, like identity management or accounting.
- **External System Integration** – they are integrated into the system to extend functionality beyond internal systems, such as handling payments, verifying identities, or accessing additional data.
- **Security and Authorization** – ensures that all interactions between systems are authenticated.
- **Event Service Bus** – allows different services to communicate with each other through event-driven mechanisms.
- **Internal Applications and Databases** – systems within the organization that support the backend services, including databases and internal monitoring tools.

Initially, the development team explored Keychain sharing between the mobile app and the VisionOS app to enable seamless cross-platform authentication. However, the sharing mechanism did not work as expected. Despite efforts to investigate and resolve the issue, the complexity involved was causing significant delays in the development process. To avoid further disruption, a temporary solution was implemented. This involved creating a separate API to check whether the user is already authenticated on the mobile app before allowing login on VisionOS. This temporary solution was introduced to simplify the integration of VisionOS with the existing mobile authentication system, allowing for a more seamless login experience.

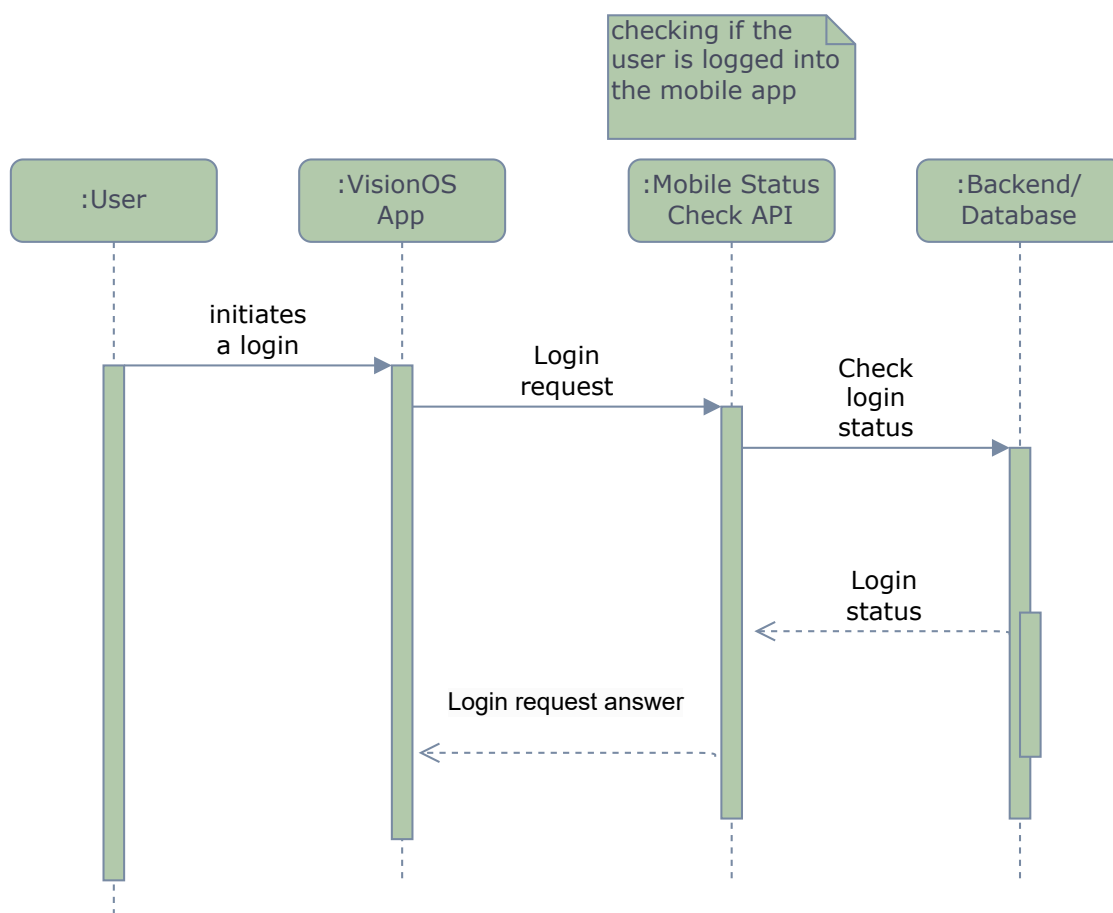


Figure 4.2: Login Process Diagram

4.2.3 Design Pattern

In addition to adopting the Model-View-ViewModel-Coordinator (MVVM-C) architecture, the VisionOS version of the app implemented the MVVM-C pattern to improve the separation of concerns, particularly in navigation. MVVM-C introduces the Coordinator component, which is responsible for managing the navigation flow between different screens, keeping the ViewModel focused on the business logic and data binding.

In addition to the MVVM-C pattern, was also implemented Interactors to further decouple business logic from the ViewModel. The Interactors are responsible for handling the core business logic and interacting with data sources such as APIs and databases. This ensures that the ViewModel remains focused on preparing data for the UI, while the Interactor manages complex operations like fetching data, processing it, and returning the results to the ViewModel.

- **Model** – handles data and business logic, interacting with services or APIs.
- **View** – represents the UI layer, displaying data provided by the ViewModel and forwarding user interactions.
- **ViewModel** – acts as the intermediary between the View and the Interactor, managing the presentation logic and preparing data for display. It decouples the user interface

from the business logic and data retrieval, ensuring that the View focuses solely on user interactions while the ViewModel handles how data is presented.

- **Coordinator** – manages the navigation flow, orchestrating transitions between views and decoupling navigation logic from the ViewModel.
- **Interactor** – handles the business logic, managing the retrieval and processing of data from APIs or databases. It decouples data access and business operations from the ViewModel, ensuring the ViewModel remains focused on presentation logic, without needing to manage or know the details of data fetching.

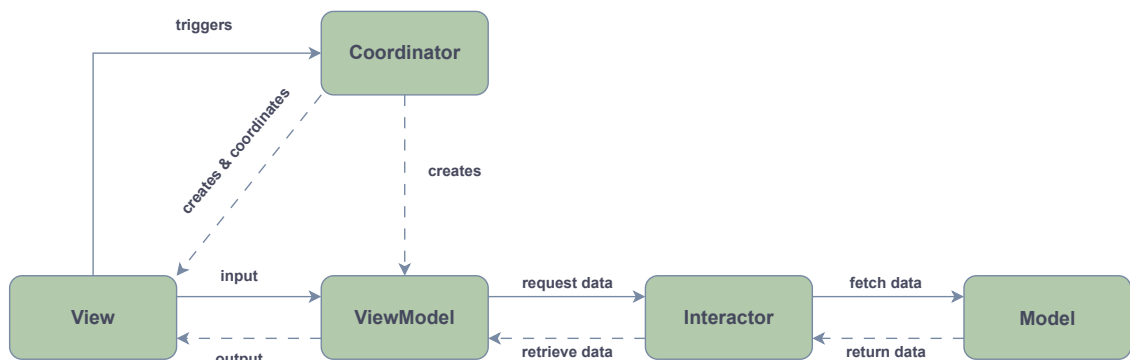


Figure 4.3: MVVM-C Diagram

4.2.4 User Interaction Layer

The VisionOS version redesigned interactions around spatial computing, where users navigate and interact with content using gestures and voice input. This interaction layer replaced the touch-based model used in mobile, taking advantage of Vision Pro's sensors to create a more immersive experience.

4.2.5 Tools

The development of ebankIT's mobile banking application to VisionOS required the use of several key tools and frameworks. Each was important in adapting the mobile app for the new environment while ensuring it remained functional and efficient. Below is a summary of the tools used and their roles in the development process:

Tool	Description
SwiftUI	SwiftUI was chosen as the primary framework for building the user interface due to its declarative syntax and ease of use. It allows developers to define the interface as a function of the app's state, automatically updating the view when the underlying data changes.
Xcode	Xcode, Apple's IDE, was the development environment used throughout the project. It supports building software across all of Apple's platforms, including VisionOS.
Swift	Swift was the main programming language for the application, known for its modern syntax, performance, and safety features.
SPM	SPM is a tool for managing dependencies in Swift projects. It was used to integrate external libraries, simplifying dependency management within Xcode, as these libraries are available for VisionOS through SPM.

Table 4.1: Tools Used in the Development of the VisionOS Application

4.2.6 Tools

4.3 Functionalities

This section provides a detailed overview of the key functionalities available in the VisionOS version of the application. The features are designed to ensure a seamless user experience, leveraging VisionOS-specific capabilities such as gesture-based interactions and OpticID for biometric authentication.

Functionality	Description	VisionOS-specific
Login	Login using username and password, checking if the user is logged in on the mobile app.	-
PIN or Biometric Screen	Redirects to the PIN screen or uses biometric authentication (OpticID) if the user is logged in.	OpticID for authentication
Dashboard	Home page showing accounts, animated graphs, favorite transactions, and recent operations.	Animated 3D graphs
Products Tab	Displays financial product types and detailed information for each one.	-
Transfers	Allows users to make financial transfers between accounts.	Gesture-based interaction only
Profile	Profile tab for logging out of the application.	-

Table 4.2: Application Functionalities for VisionOS

4.4 Technical Challenges

This section explains the main difficulties faced during the project, focusing on the issues that came up during the development process and how they were handled to ensure the app worked smoothly on the new platform.

4.4.1 Compatibility of External Libraries with VisionOS

One of the main challenges we faced was ensuring that the external libraries used in the mobile version were compatible with VisionOS. Some libraries, like AppAuth, initially lacked VisionOS support, which slowed down the development process. The developers of AppAuth created a separate branch specifically for VisionOS to address this issue, can be seen at (OpenID 2021). Although this helped make the library functional on VisionOS, it took time and caused delays in our progress.

4.4.2 Switching from CocoaPods to SPM

Our internal libraries were set up using **CocoaPods**, but many of the external libraries we used hadn't yet supported VisionOS through CocoaPods. This meant we had to remove those external libraries from CocoaPods and switch to SPM. This change was necessary to get the libraries working with VisionOS. While this solved the compatibility issue, it added extra work for us to manage dependencies in a new way.

CocoaPods is a dependency manager for Swift and Objective-C projects. It simplifies the process of integrating third-party libraries by automatically downloading and configuring them into your Xcode project, ensuring compatibility and ease of use.

4.4.3 Making the Project Recognize the Internal Libraries

Another challenge was getting our VisionOS project to recognize our internal libraries. To do this, we had to create a new **workspace** and add each library manually, one by one, including the VisionOS project itself. This allowed us to link the necessary frameworks and libraries the app required to function properly.

A **workspace** in Xcode is a container that allows multiple projects to be organized and managed together. It helps to link related projects, making it easier to share resources and dependencies between them, all within a single environment.

4.4.4 Adapting UIKit Architecture to SwiftUI

The shift from UIKit to SwiftUI was another challenge, as some of the logic that worked well in UIKit needed to be adjusted for SwiftUI. SwiftUI uses a different approach to building user interfaces, so we had to rework parts of the app to match its architecture, making sure everything functioned smoothly in the new environment.

```
1 struct WelcomeView: View {
2
3     @EnvironmentObject private var appRootManager: AppRootManager
4     @StateObject private var viewModel = WelcomeViewModel(dependencies:
5     nil)
6
7     var body: some View {
8         LottieView(animation: .named("Logo_ebankit"))
9             .playing()
10            .animationSpeed(0.6)
11            .animationDidFinish({ _ in
12                viewModel.lottieEnded()
13            })
14            .frame(width: 300, height: 300)
15            .onAppear{
```

```

15         viewModel.didFinishRequests = {
16             appRootManager.currentRoot = viewModel.hasLoggedIn ?
17             .pinDialler : .login
18         }
19     }
20 }

```

Listing 4.1: Welcome View in SwiftUI

```

1  open class WelcomeViewController: UIViewController, Viewable {
2      private(set) public var viewModel: WelcomeViewModelProtocol
3      @IBOutlet public weak var centerLabel: UILabel!
4      @IBOutlet public weak var backgroundImage: UIImageView!
5
6      #if canImport(Lottie)
7          private var lottieView: LottieAnimationView = {
8              let animationView = LottieAnimationView()
9              animationView.translatesAutoresizingMaskIntoConstraints = false
10             animationView.contentMode = .center
11
12             if Constants.targetName == "MobileBanking" {
13                 animationView.animation = LottieAnimation.named(Constants.
14                 lottie)
15             } else if Constants.targetName == "NebulaBank" {
16                 animationView.animation = LottieAnimation.named(Constants.
17                 lottieNebula)
18             }
19
20             return animationView
21         }()
22     #endif
23
24     required public init(viewModel: WelcomeViewModelProtocol, nibName:
25     String? = nil) {
26         self.viewModel = viewModel
27         if let nibName = nibName {
28             super.init(nibName: nibName,
29                 bundle: Bundle(for: Self.classForCoder()))
30         } else {
31             super.init(nibName: "WelcomeViewController",
32                 bundle: Bundle(for: WelcomeViewController.self))
33         }
34     }
35
36     required public init?(coder: NSCoder) {
37         fatalError("init(coder:) has not been implemented")
38     }
39
40     open override func viewDidLoad() {
41         super.viewDidLoad()
42         navigationController?.navigationBar.isHidden = viewModel.
43         navigationBarIsHidden
44         setupUI()
45         setupBindings()
46     }
47
48     open func setupUI() {
49         view.applyTheme("WelcomeView")
50     }
51 }

```

```
47 #if canImport(Lottie)
48     centerLabel.isHidden = true
49
50     view.addSubview(lottieView)
51     view.addConstraints([
52         lottieView.topAnchor.constraint(equalTo: view.topAnchor),
53         lottieView.leadingAnchor.constraint(equalTo: view.
54     leadingAnchor),
55         lottieView.trailingAnchor.constraint(equalTo: view.
56     trailingAnchor),
57         lottieView.bottomAnchor.constraint(equalTo: view.
58     bottomAnchor)
59     ])
60
61     lottieView.animationSpeed = Constants.lottieDuration
62     lottieView.play(completion: { [weak self] _ in
63         self?.viewModel.lottieEnded()
64     })
65 #else
66     backgroundImage.applyTheme("PreLoginBackground")
67     backgroundImage.isHidden = false
68 #endif
69 }
```

Listing 4.2: Welcome View in UIKit

SwiftUI and **UIKit** are two frameworks used to build user interfaces in Apple's ecosystem, but they follow different approaches:

- **SwiftUI** – adopts a declarative approach, where the UI is defined as a function of its state. Developers specify how the UI should look based on data, and the framework automatically handles updates when that data changes.
- **UIKit** – follows an imperative approach, where developers must explicitly define and manage the entire UI and its updates. This provides greater flexibility and control but often results in more verbose and complex code.

4.5 Work Plan

Here we have an estimated timeline, considering the app already exists on iOS and needs to be adapted and optimized for visionOS, along with challenges like certain libraries (e.g., AppAuth) not yet supporting visionOS:

Phase 1 - Research and Planning

During this phase, the main focus was evaluating the existing iOS app functionalities and determining how they could be adapted for VisionOS. This involved assessing the technical requirements for VisionOS and identifying potential challenges related to the compatibility of libraries, such as AppAuth. Alternative strategies were developed to address any limitations, and a detailed project plan was created, considering the beta state of VisionOS and the unavailability of some necessary libraries.

Phase 2 - UX/UI Design

During this phase, the design team created the app's screens specifically for VisionOS, following the platform's design guidelines. The focus was on adapting the user interface to the unique 3D spatial environment of VisionOS while ensuring seamless gesture-based interactions and a smooth user experience.

Phase 3 - Development

In this phase, the development team was able to utilize all the necessary libraries that were previously unavailable for VisionOS. This allowed for a smoother integration of functionalities from the mobile app into the VisionOS version. With these libraries now accessible, the app's features were successfully adapted to the new platform, ensuring compatibility and consistent performance with VisionOS's environment.

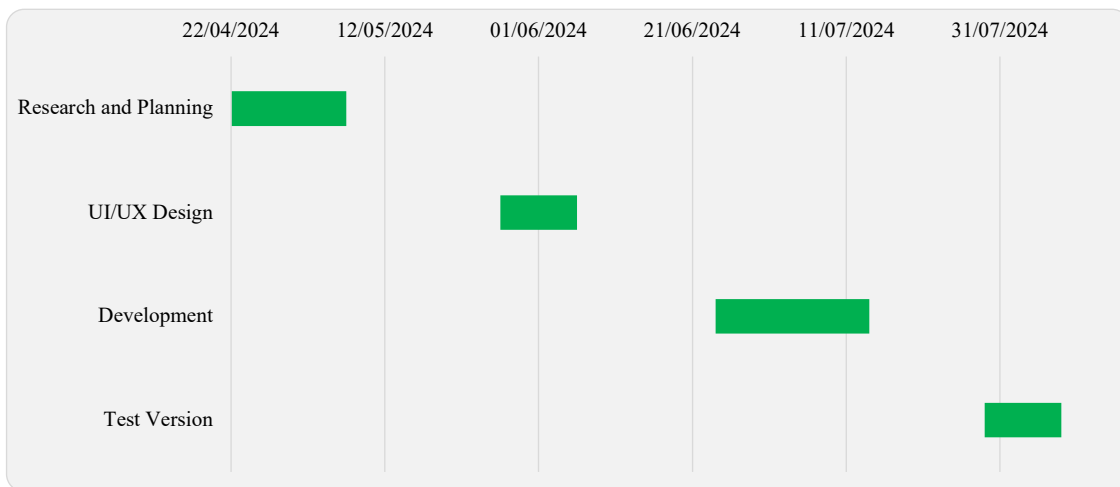


Figure 4.4: Work Plan - Gantt Diagram

4.6 Implementation

This section presents the main screens of the VisionOS version of the banking app, along with descriptions of the core functionalities. The screens include the login, dashboard, products, transfers, and profile tabs, each designed to provide an immersive and intuitive user experience using gesture-based interactions. The app retains the essential features from the mobile version, adapted for VisionOS.

4.6.1 External Libraries

The external libraries used in both the mobile and VisionOS versions of the app. Libraries such as **AppAuth**, **JWT** and others more were integrated to ensure the same functionality and performance across both platforms.

Library	Description
AppAuth	Used for managing secure user authentication, handling the login process and session management.
JSON Web Token (JWT)	Implemented for securely transmitting and verifying user data, ensuring sensitive information is protected during interactions with the backend.
Alamofire	Utilized for handling network requests, allowing efficient communication between the app and backend services.
Lottie	Used for rendering smooth animations within the app, enhancing the user experience with visual feedback, particularly in the dashboard.

Table 4.3: External Libraries Used in Mobile and VisionOS Versions

4.6.2 Library Integration with SPM

As mentioned earlier, **SPM** was used for installing the libraries. To use SPM, you start by opening your project in Xcode and navigating to **File > Add Packages**. In the window that appears, you can enter the URL of the package repository you want to add, such as the GitHub URL for a library like Alamofire. Once Xcode fetches the package information, you select the appropriate versioning rules (such as using the latest stable version or specifying a version range) and add it to your project.

After the package is added, it will appear under the Swift Packages section in your project settings. From there, you can manage updates or remove the package if needed. In your code, you simply import the package using its name, just as you would with any built-in Swift framework

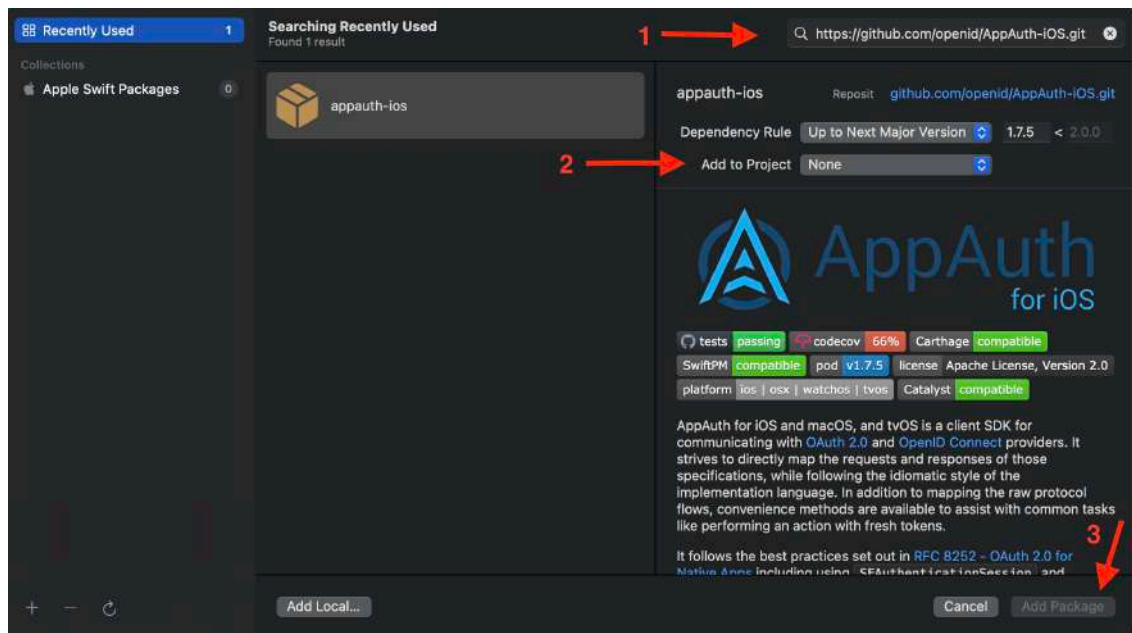


Figure 4.5: Installing AppAuth using SPM

4.6.3 Login

This is the login screen, where users are prompted to enter their username and password. Once the credentials are submitted, the system checks if the user is already logged into the mobile app. If an active session is detected on the mobile platform, the user is allowed to proceed with logging into the VisionOS app.

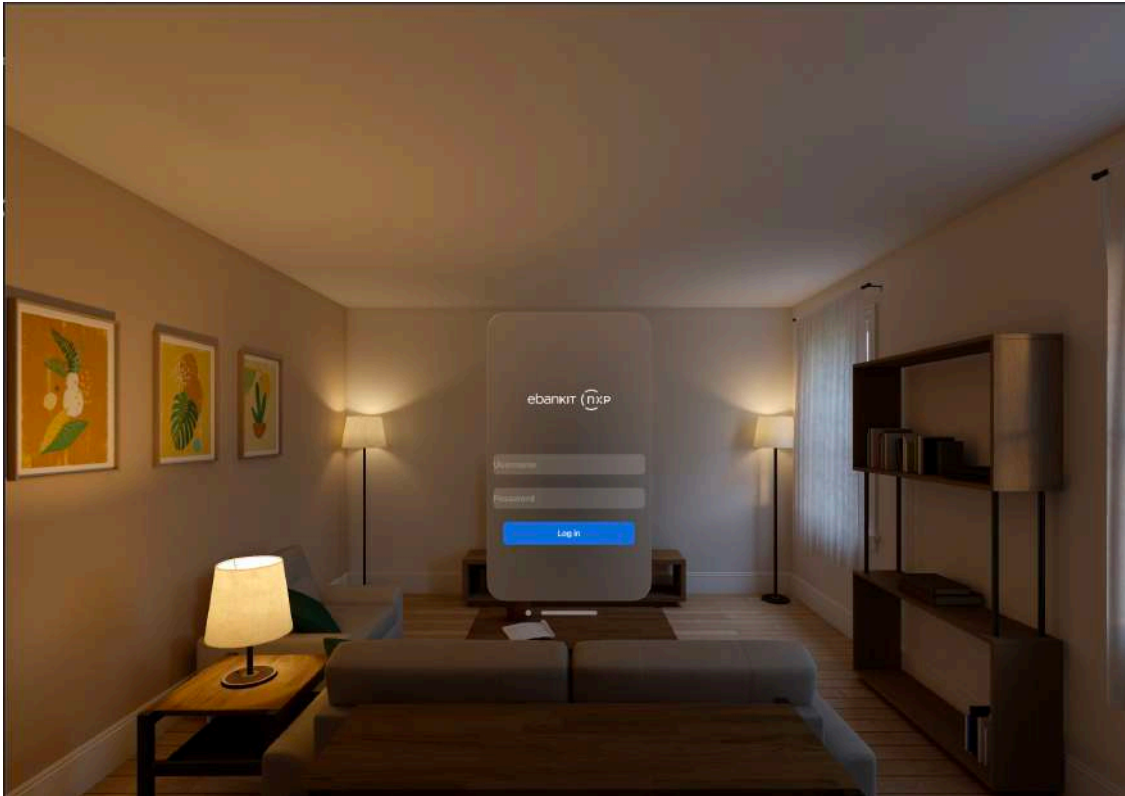


Figure 4.6: Login Window

Login Failure

This is the screen that appears if the user has not yet logged into the mobile app. In this case, the app displays an error message informing the user that they must first log in to the mobile app before proceeding with the VisionOS version.

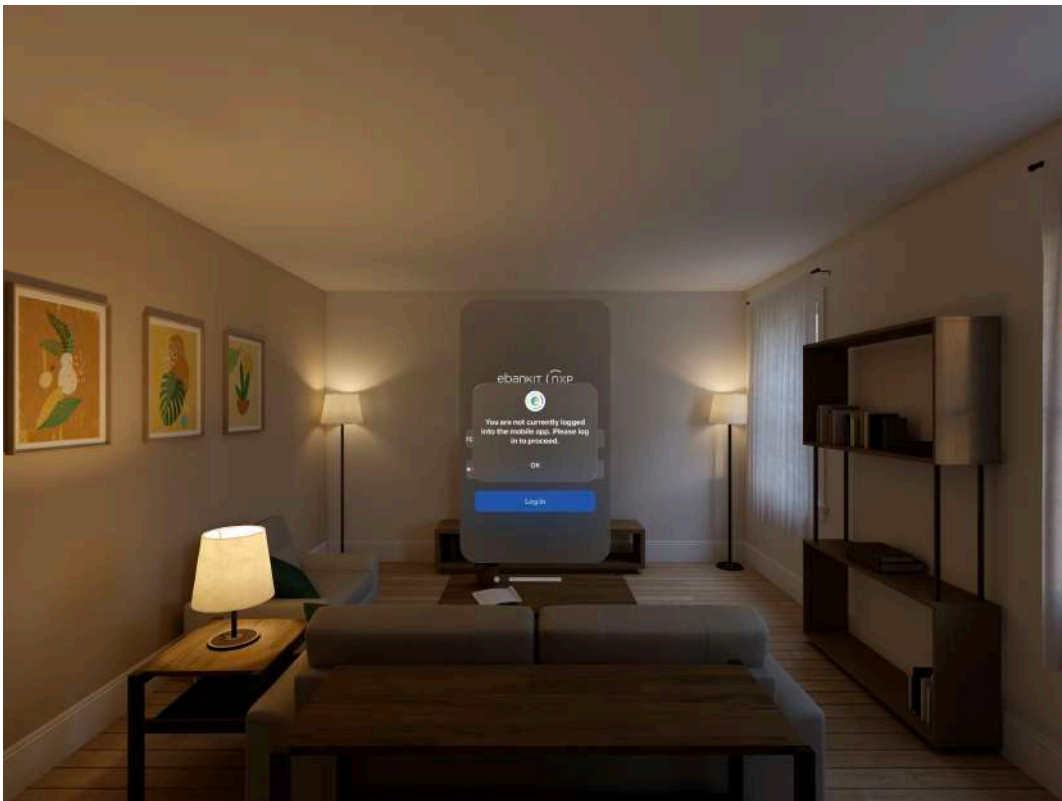


Figure 4.7: Login Failure Alert

4.6.4 Pin Dialer

After successfully logging in with the username and password, and verifying that the user is already authenticated in the mobile app, the system stores the user's information on the device. The user is then redirected to the PIN dialer screen, where they must enter the same PIN used for the mobile app. Additionally, there is an option to log in using Optic ID.

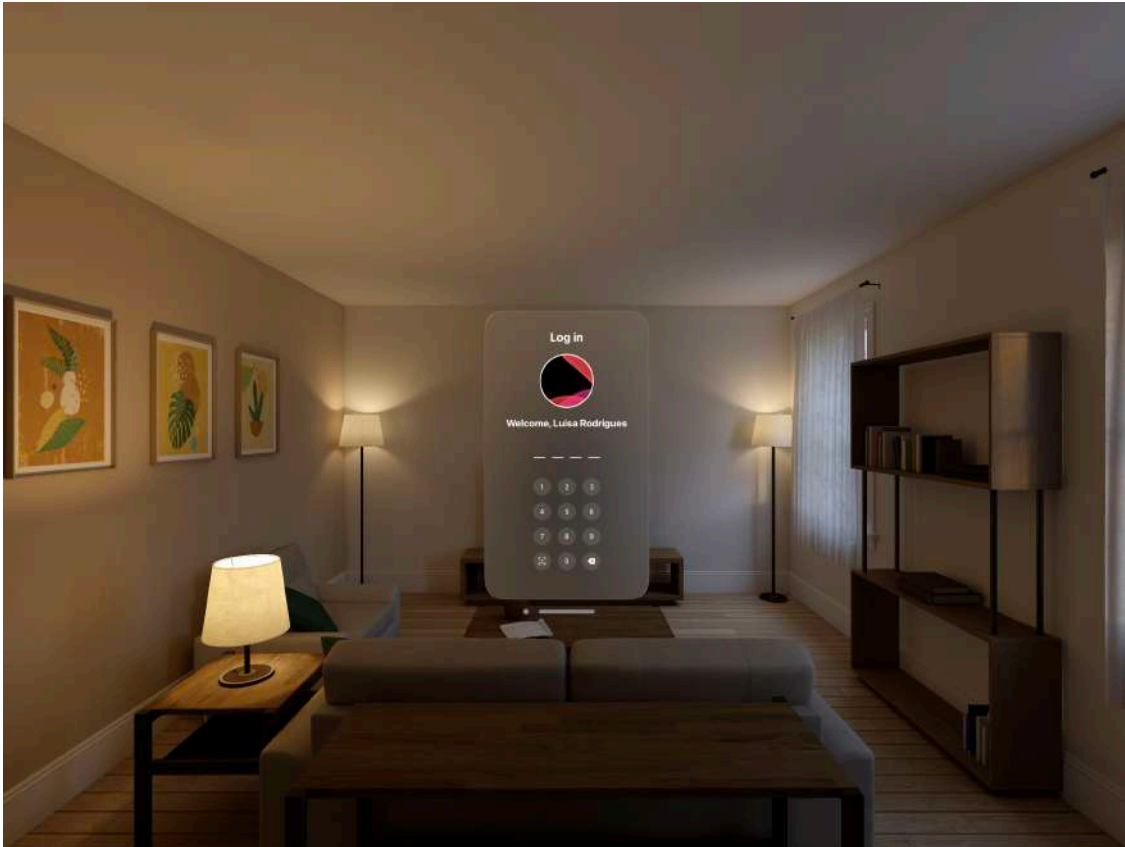


Figure 4.8: Pin Dialer Window

Pin Dialer Optic ID

This screen is displayed after the user selects the option to log in using Optic ID. Once the biometric scan is successfully completed, confirming the user's identity, the system seamlessly redirects the user to the app's main screen. This feature provides a quick and secure login method, enhancing the overall user experience by minimizing the need for manual input while ensuring secure access.

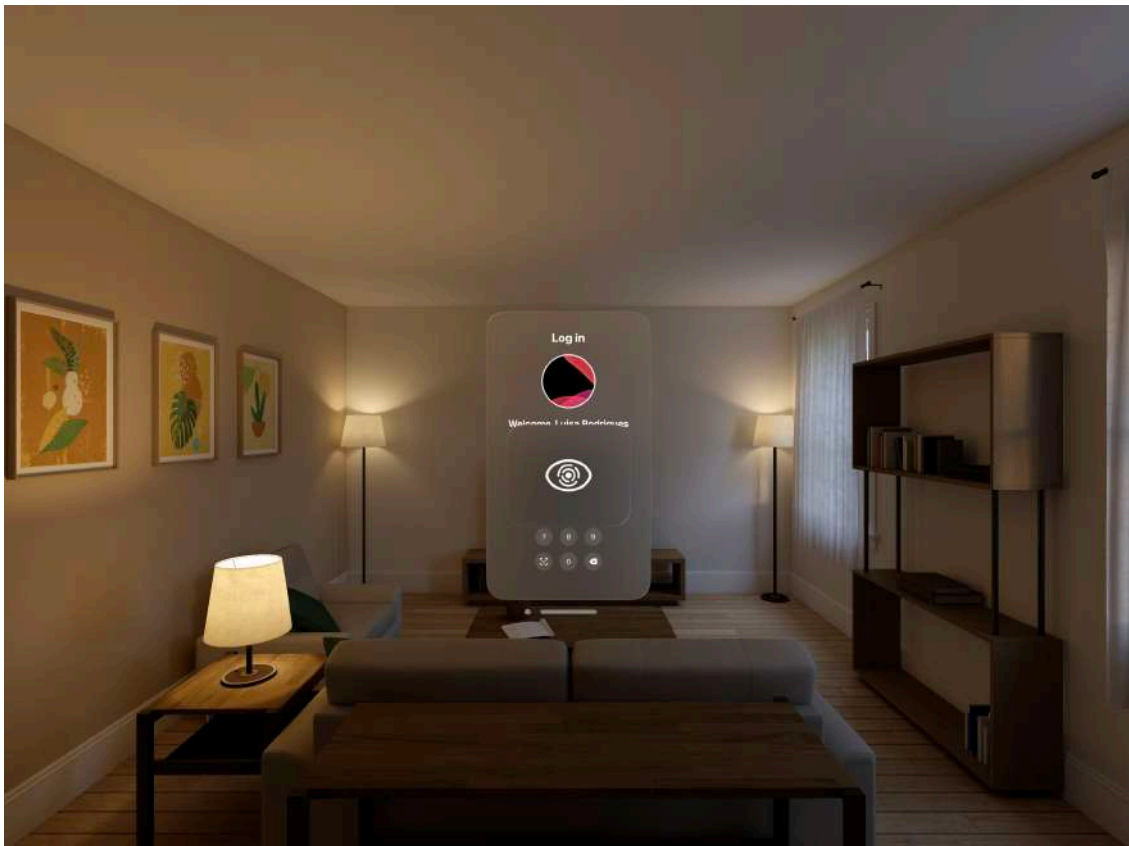


Figure 4.9: Pin Dialer Optic ID

Pin Dialer Log out

There is also an option to switch users, allowing the current user to log out of the system. Upon selecting this option, the user is immediately logged out, and the system clears any stored session data. The user is then redirected to the login screen, where another user can input their credentials to access the app.

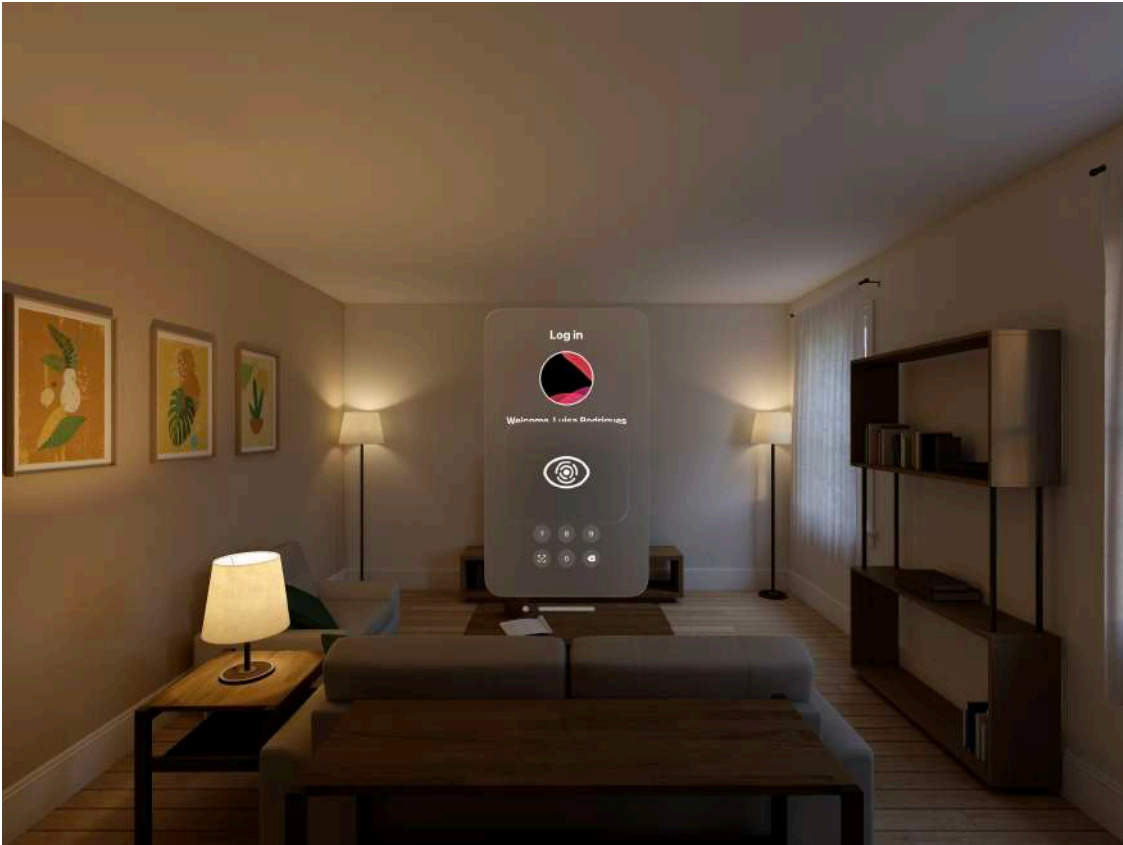


Figure 4.10: Pin Dialer Optic ID

4.6.5 Dashboard

The main screen is organized into a TabView with four distinct options, with the Dashboard being the default view. In the Dashboard, users can easily access an overview of their financial information. It displays all linked cards, along with their respective balances over the past 30 days, allowing users to track their spending trends at a glance. In addition to card balances, the Dashboard also highlights the most recent transactions, giving users a quick snapshot of their latest financial activities. Furthermore, users can view a curated list of their favorite transfers, making it more convenient to initiate frequent transactions directly from this screen.



Figure 4.11: Dashboard Window

4.6.6 Products

The Products tab allows users to view a comprehensive list of their financial products, including credit cards, debit cards, and other types of accounts. This section provides an organized and detailed overview of all the cards linked to the user's account. By selecting a specific card, users can easily access detailed information and manage their financial products. The tab simplifies navigation by categorizing the various cards, making it easier for users to switch between them and view the relevant information without clutter or confusion. Each card can be selected to reveal more detailed account information, providing a straightforward and efficient way to manage multiple financial products in one place.

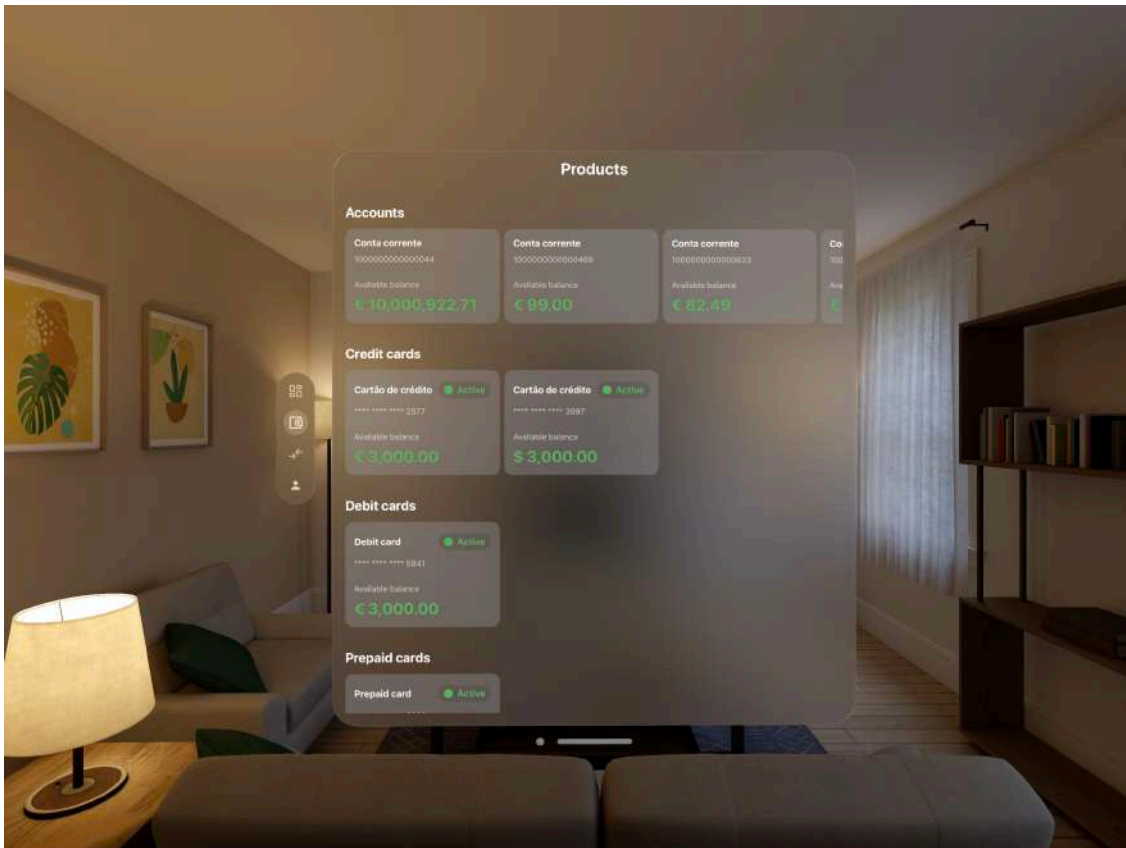


Figure 4.12: Products Window

4.6.7 Account Details

The Products tab offers users a clear and organized view of all their financial products, including credit cards, debit cards, and other account types. This tab is designed to provide users with a structured and easy-to-navigate overview of their financial products, linking all cards associated with the account in one place. By simply selecting a card, users can access more detailed information, such as recent transactions, available balance, and account-specific details.

Each card is presented in a categorized format, helping users switch between different products seamlessly without overwhelming them with unnecessary information. Once a card is selected, the same window updates to display the relevant information for that product, allowing users to quickly manage their financial assets.

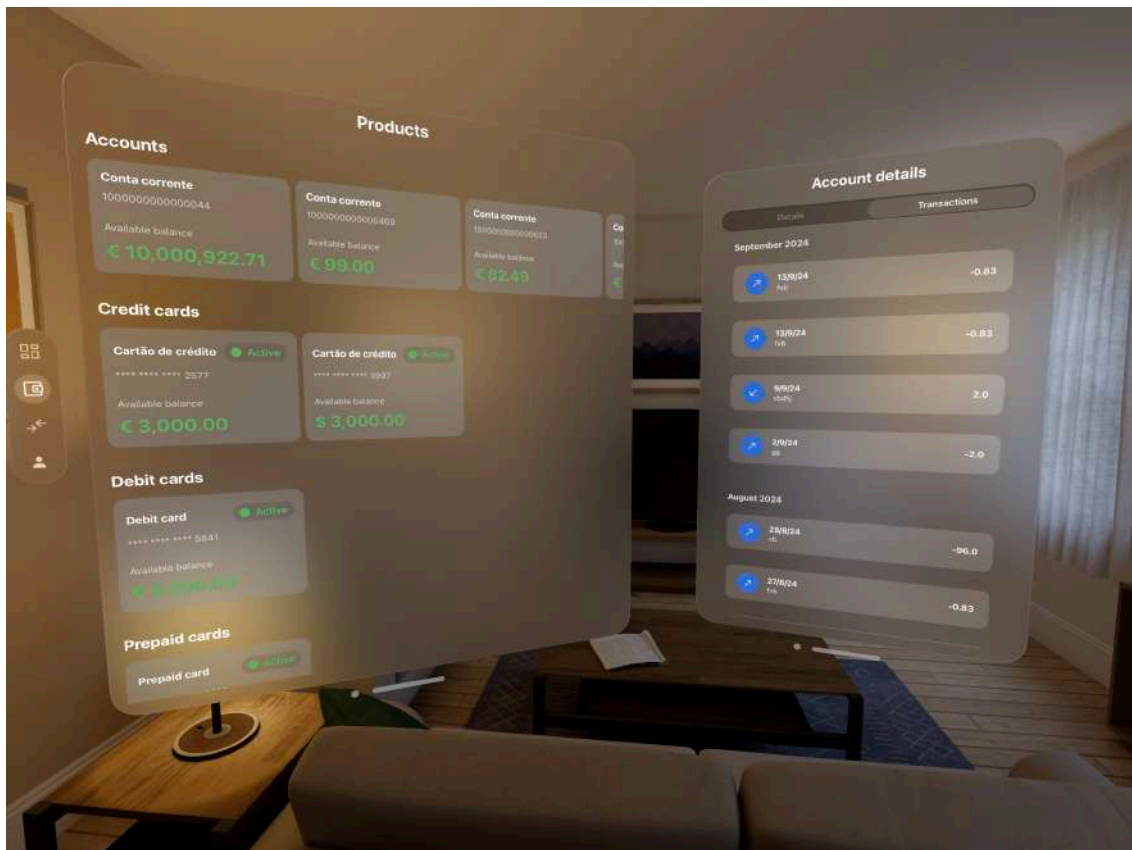


Figure 4.13: Product Details Window

4.6.8 Move Money

The next option is the Move Money tab, which initially displays the user's primary account. If any accounts have been marked as favorites in the mobile app, those will also appear in this tab for easy access. In addition to showing favorite accounts, the tab also provides a list of favorite transactions and scheduled transactions. However, at this time, the VisionOS app does not support scheduling new transactions, meaning users can only view previously scheduled transactions but cannot create new ones.

There is also a prominent button, highlighted in red, displaying the name of the user's primary account. When clicked, this button opens a window where the user can start the process of making a transfer.

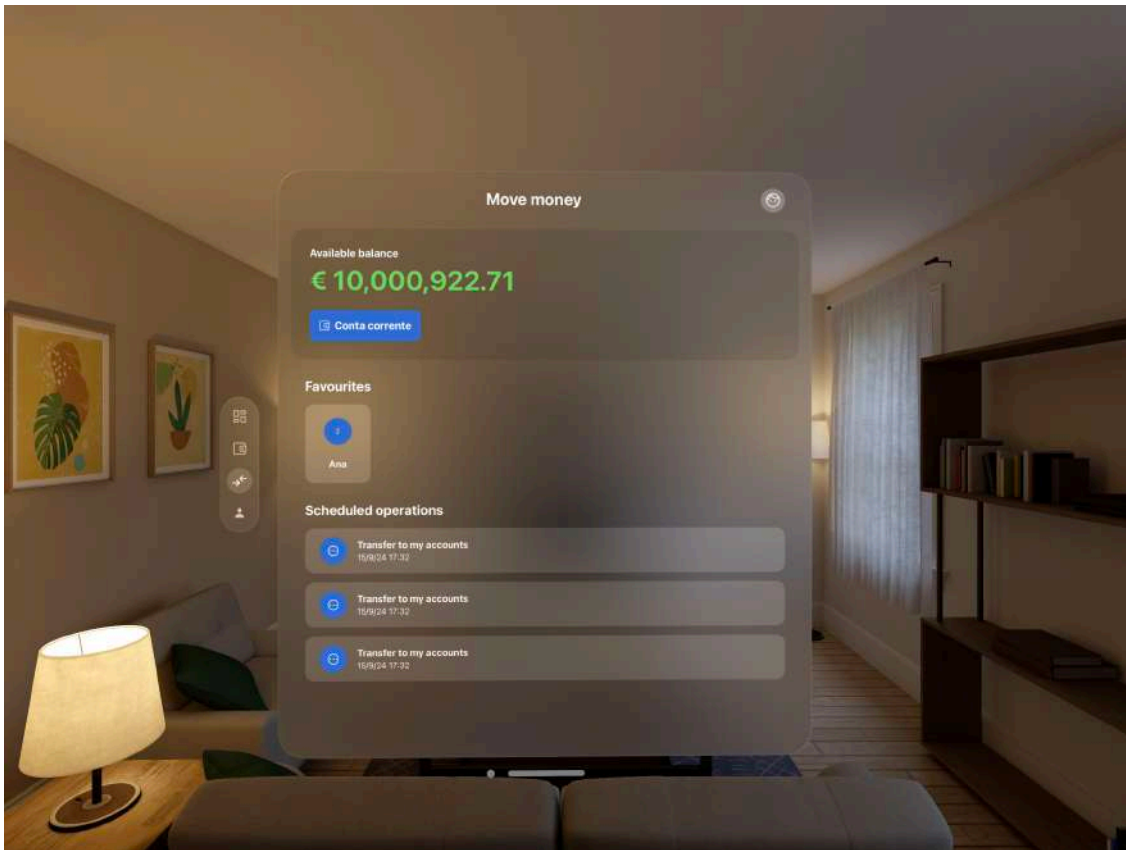


Figure 4.14: Move Money Window

4.6.9 Transfer to my Account

When the user clicks on the button displaying their account, a window titled Transfer to My Account opens, allowing them to initiate a transfer between their own accounts. In this window, users can utilize the drag and drop feature to select both the account they want to transfer from and the destination account. This intuitive drag-and-drop functionality simplifies the process of choosing the correct cards or accounts for the transfer.

Additionally, there are pre-defined custom descriptions available that users can drag and drop into the appropriate field, avoiding the need to manually type a description for the transfer. There is also a dedicated field for users to enter the transfer amount.

The transfer button remains disabled until all required fields (source account, target account, description, and amount) are filled in. Once all fields are completed, the button becomes active, allowing the user to proceed with the transfer.

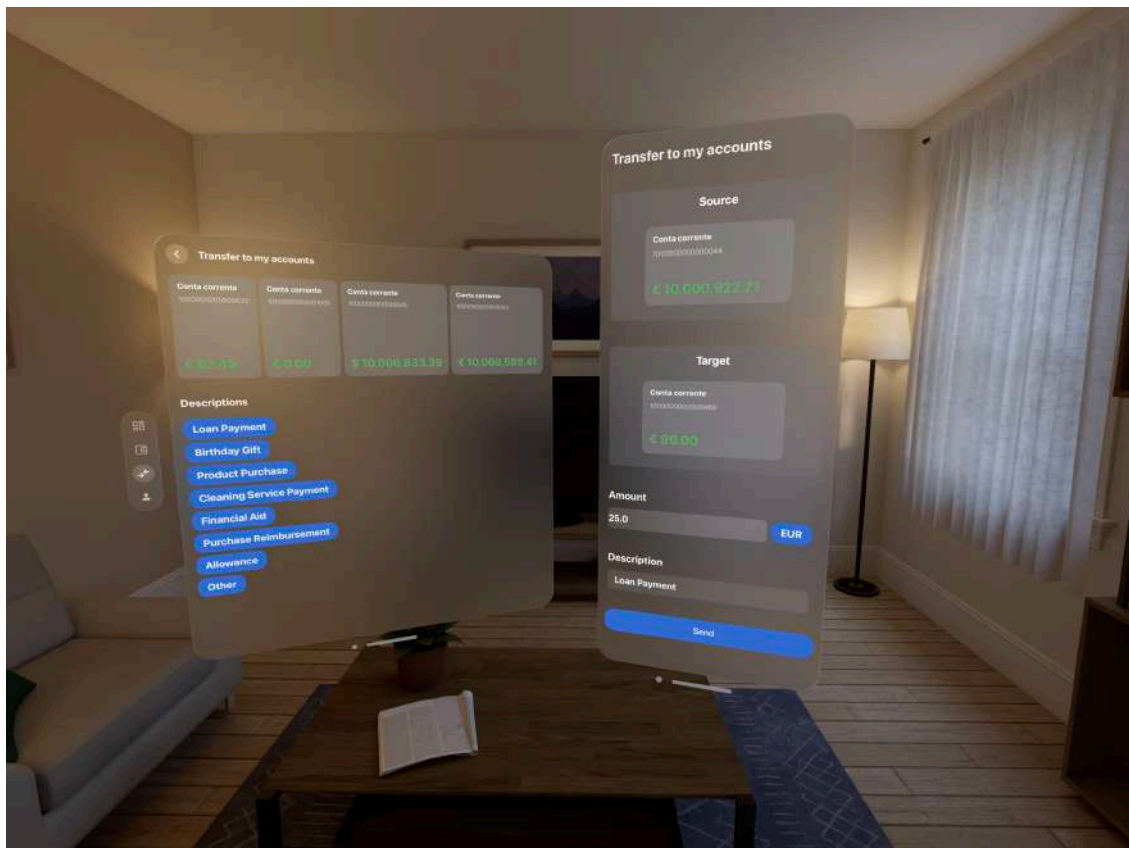


Figure 4.15: Transfer to my Account Window

Transfer to my Account Empty

This is the Transfer to My Accounts window in its initial state, before all the required fields have been completed. At this stage, the user is prompted to select both the source and destination accounts, use the drag and drop feature to choose a card for the transfer, add a description, and enter the transfer amount. The transfer button remains inactive until all necessary fields are filled in.

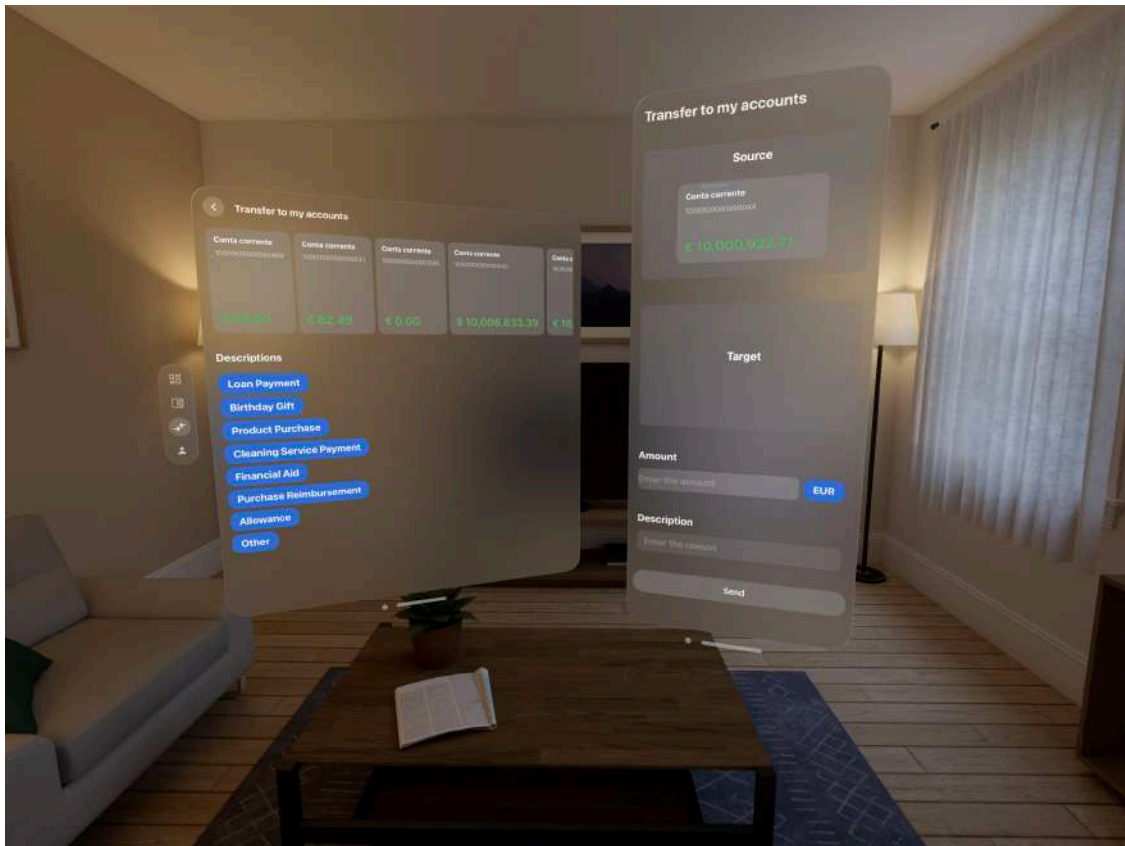


Figure 4.16: Transfer to my Account Empty

Transfer to my Account Confirmation

Once all the fields are filled in, and the user clicks Send, the system prompts for confirmation via Optic ID. This additional step ensures that the transfer is securely authorized before being processed.

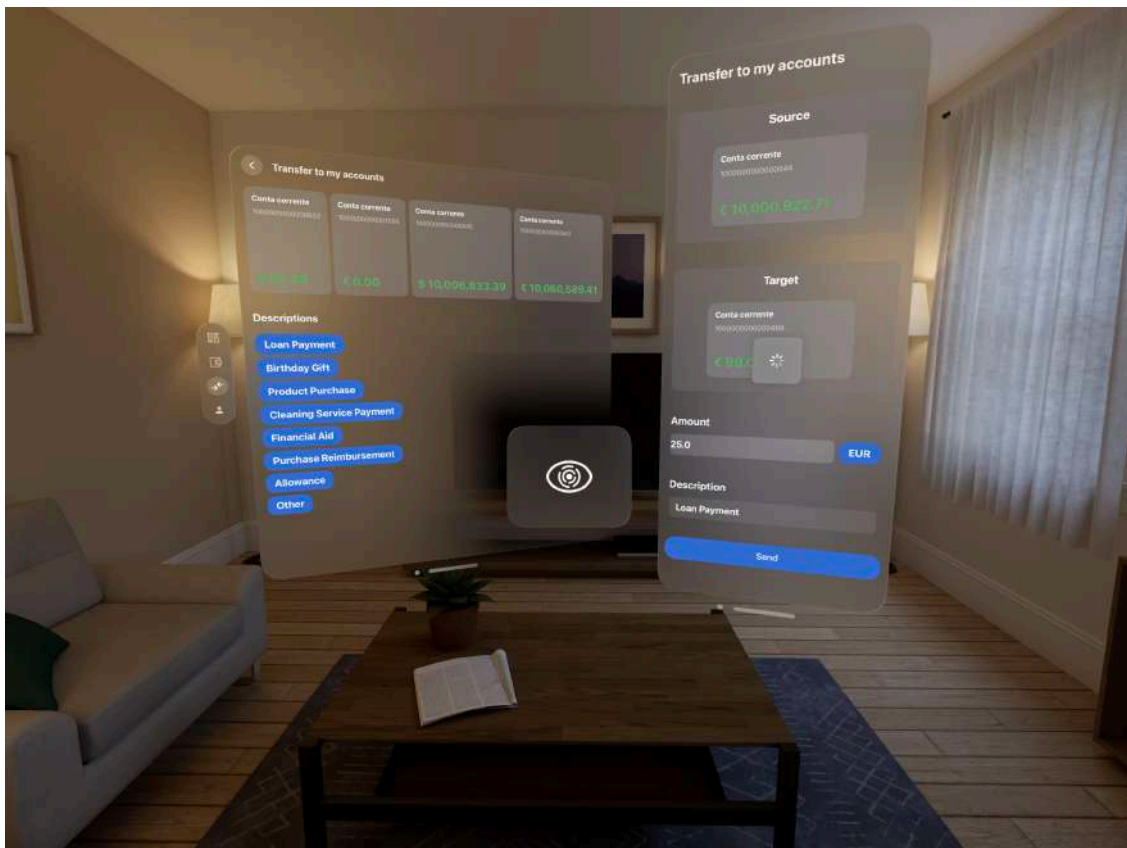


Figure 4.17: Transfer to my Account Optic ID Scan

Transfer to my Account Success

After the transfer is successfully completed, a success window is displayed, confirming that the transaction was processed without any issues.

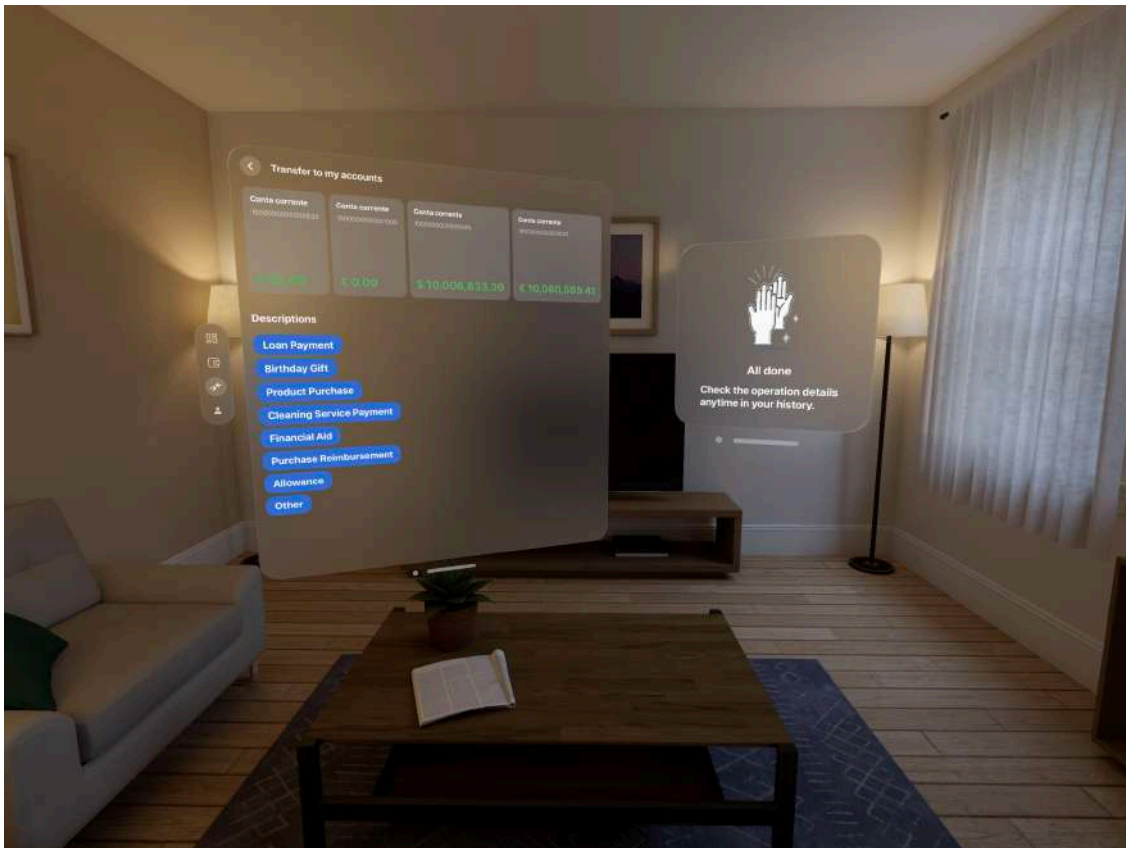


Figure 4.18: Transfer to my Account Success

4.6.10 My Profile

Lastly, we have the My Profile tab, where users can view basic account information such as their profile picture, username, and the type of contract they are using. This tab also includes a logout button. Once the user logs out, they are redirected to the PIN dialer screen, where they would need to log in again or switch users.

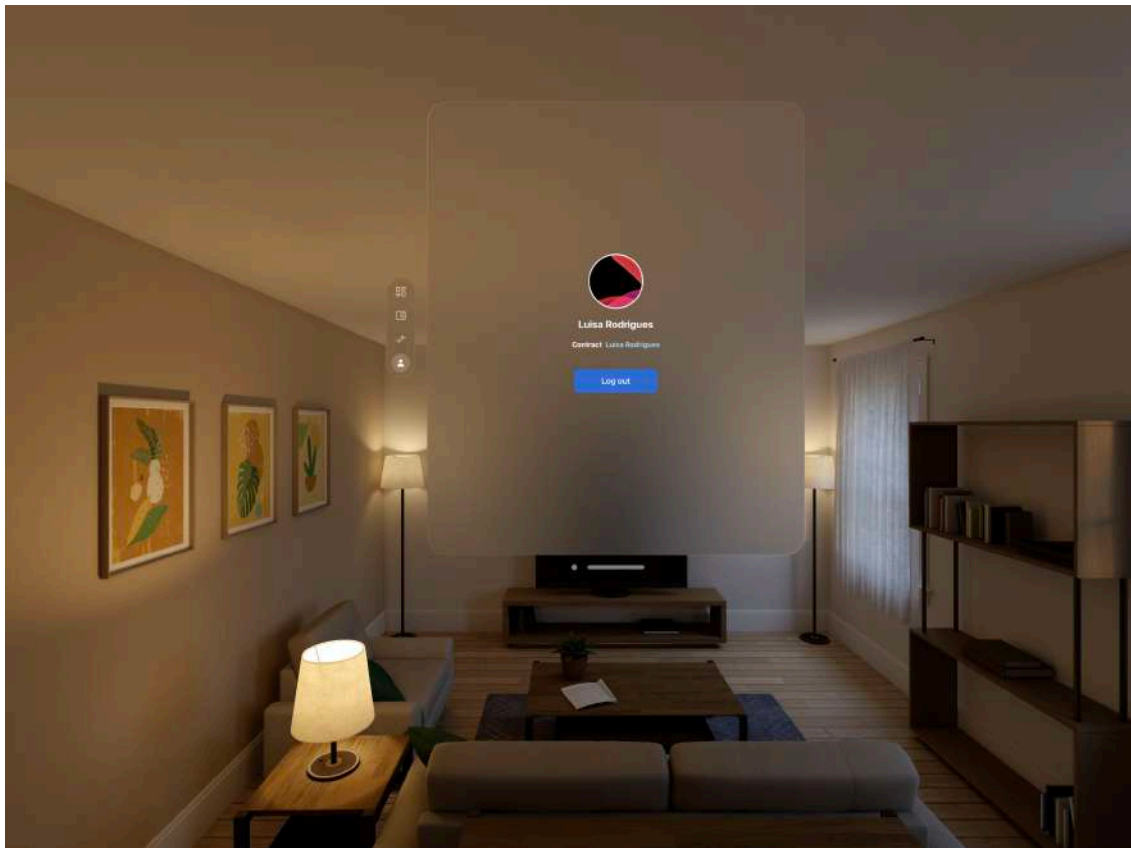


Figure 4.19: My Profile Window

In summary, each tab and screen within the VisionOS app has been thoughtfully designed to provide an intuitive, user-friendly experience, while maintaining the core functionalities found in the mobile version. From managing accounts and transfers to accessing profile information, every interaction is streamlined to take full advantage of VisionOS's immersive capabilities. The inclusion of features like Optic ID for secure authentication and drag-and-drop functionality ensures that users can manage their finances with ease and confidence. With all features fully implemented and operational, the VisionOS version of the app is now fully functional, offering users an engaging and interactive way to handle their financial activities seamlessly.

Chapter 5

Conclusion

This dissertation presented an innovative solution by developing a banking application specifically for VisionOS, leveraging emerging technologies such as augmented reality (AR) and artificial intelligence (AI). Despite encountering several challenges, such as adjusting third-party libraries and ensuring user data privacy and security in an AR/VR environment, we were able to successfully achieve the main objectives of the project. Key functionalities, such as biometric authentication with OpticID and gesture controls, were successfully implemented, demonstrating the potential for intuitive and personalized financial management in an immersive environment.

While most objectives were met, certain features, like the virtual assistant, were not included in the final version. This was primarily due to the decision to prioritize other core functionalities and the complexities involved in integrating this feature. The virtual assistant remains a valuable addition for future iterations, as it holds potential to further enhance the user experience.

Despite these limitations, the technical robustness of the developed solution is evident, and the implemented features provide a strong foundation for future enhancements. The work demonstrates how VisionOS can significantly enhance user experience in the banking sector, offering new opportunities for interaction and financial data management.

In summary, this dissertation contributes to the advancement of immersive banking applications and paves the way for future research in the field of augmented and virtual reality technologies applied to the financial sector. The successful implementation of several core features, despite some setbacks, highlights the potential of VisionOS integration. Moving forward, further investment in usability research, accessibility, and economic impact will be essential to ensure such innovations can be widely adopted and optimized for real-world application.

5.1 Future Work

There are several improvements that could be made to further refine both the user experience and the security of the platform. Some key areas for future work include:

- **Virtual Assistant** – a future addition could be an AI-powered virtual assistant. This assistant would assist users by answering questions, guiding them through tasks, and performing certain actions, making the app more intuitive and interactive.

- **Improved Security with MFA** – another potential improvement would be the implementation of **MFA**. This would add an extra layer of security, ensuring that users are properly authenticated on the mobile app before gaining access to the VisionOS app.
- **Additional Features** – a further improvement could involve adding more functionalities specifically for the VisionOS version of the app. This could include new interactions, 3D visualizations, or other features tailored to fully utilize VisionOS's unique capabilities, further improving the overall user experience.

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