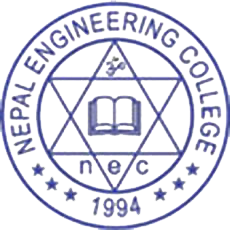
Project III Final Report on

**AR STORE**

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Submitted to

**Department of Computer Science and Engineering**

**Nepal Engineering College**

in Partial Fulfillment of the

Requirements for the Degree of B.E. in Computer

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Sincerely,

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# Abstract

The AR Furniture Store Ecommerce Website project revolutionizes online furniture shopping by introducing augmented reality (AR) technology, enabling users to visualize furniture within their own living spaces for informed decisions. Developed with React for the front-end and Node.js for the back-end, it seamlessly integrates WebXR Device API and Three.js for immersive AR experiences directly in the web browser. The project prioritizes ecommerce functionality, ensuring secure payment processing with Khalti and user authentication via JSON Web Tokens. Through this amalgamation of innovative technology and robust infrastructure, the project exemplifies the future of ecommerce, where immersive experiences and seamless functionality converge to deliver a truly satisfying shopping experience.

[**Keywords:** Augmented Reality,WebXR, ARCore, ARKit, LiDAR, Node.js, PostgreSQL, Three.js]

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Abbreviations

**AR** - Augmented Reality

**HTML** - Hypertext Markup Language

**CSS** - Cascading Style Sheets

**JSON** - JavaScript Object Notation

**API** - Application Programming Interface

**XR** - Extended Reality

**VIO -** Visual-Inertial Odometry

**SLAM -** Simultaneous Localization and Mapping

# : Introduction

The AR Furniture Store Ecommerce Website project represents a significant endeavor in the realm of modern ecommerce platforms, aiming to revolutionize the way customers shop for furniture online. In an era where technological advancements continually reshape consumer behaviors and expectations, the integration of augmented reality (AR) technology emerges as a transformative solution to bridge the gap between virtual and physical shopping experiences.

The conventional online furniture shopping experience often leaves customers grappling with uncertainty regarding the suitability of products for their living spaces. This lack of tangibility and visual context frequently results in hesitancy and dissatisfaction, leading to a higher rate of product returns and diminished customer satisfaction. Recognizing these challenges, our project endeavors to address this critical issue by leveraging AR technology to provide users with a realistic and immersive visualization of furniture products within their own homes.

By incorporating AR functionality into an ecommerce website, users gain the ability to interact with virtual furniture models in real-world environments, allowing them to assess factors such as size, style, and compatibility with existing decor. This innovative feature empowers customers to make more informed purchasing decisions, instilling confidence, and trust in the online shopping process. Furthermore, by enhancing the user experience and reducing the likelihood of returns, the project aims to deliver tangible benefits to both customers and businesses alike.

## 1.1 Overview

Our project focuses on the development of an innovative ecommerce platform tailored specifically for the furniture industry. The project integrates innovative technologies to enhance the online shopping experience, with a particular emphasis on augmented reality (AR) functionality. By leveraging AR technology, customers can visualize furniture products in their own space before making a purchase, thereby overcoming the limitations of traditional online shopping. The project encompasses both front-end and back-end development, utilizing popular frameworks and libraries such as React, Node.js, and PostgreSQL. Through the integration of AR technology and sophisticated backend infrastructure, the project aims to revolutionize the way customers shop for furniture online, offering a seamless, immersive, and intuitive shopping experience.

## 1.2 Problem Statement

Traditional online furniture shopping platforms often fail to adequately address the inherent challenges of purchasing furniture without physically experiencing it in the intended space. Customers are frequently left with uncertainty regarding how a piece of furniture will look and fit within their home environment, leading to hesitation and an increased likelihood of returns. Additionally, the lack of interactivity and personalization in online shopping experiences diminishes customer engagement and satisfaction.

Furthermore, existing ecommerce platforms typically lack the integration of advanced technologies that could significantly enhance the shopping experience. Augmented reality (AR) presents a promising solution to these challenges by allowing customers to virtually place furniture products within their own living spaces, providing a realistic and immersive visualization experience. However, the implementation of AR technology within ecommerce platforms remains limited, primarily due to technical complexities and resource constraints.

Therefore, our project aims to address these issues by developing an ecommerce platform specifically tailored for the furniture industry, with a strong emphasis on integrating AR functionality. By combining front-end and back-end development expertise with AR technology, we seek to provide customers with a seamless and interactive online shopping experience that closely mirrors the in-store experience. Through this project, we aim to overcome the limitations of traditional online furniture shopping platforms and revolutionize the way customers shop for furniture online.

## 1.3 Objectives

To develop an innovative ecommerce platform for the furniture industry, integrating augmented reality (AR) technology to enhance the online shopping experience.

1. Develop a user-friendly ecommerce platform tailored for the furniture industry.
2. Integrate AR functionality to allow customers to visualize furniture products in their own living spaces.
3. Implement a robust backend infrastructure to support data management.
4. Design a responsive front-end interface for seamless user interaction.
5. Ensure secure user authentication mechanisms.
6. Evaluate the impact of AR technology on customer engagement and satisfaction.

## 1.4 Aims

To revolutionize the online furniture shopping experience by integrating augmented reality (AR) technology, enhancing customer engagement and satisfaction. Develop an ecommerce platform tailored for the furniture industry. Incorporate AR functionality to allow customers to visualize furniture products in their own living spaces. Create a seamless and intuitive user interface for enhanced usability. Establish a secure backend infrastructure to support data storage and management. Contribute to the advancement of ecommerce practices through documentation and insights gained from the project implementation.

## 1.5 Motivation

The motivation behind our university final year project stems from the desire to address the limitations of traditional online furniture shopping platforms. We aim to enhance the online shopping experience for customers by leveraging emerging technologies such as augmented reality (AR).

The lack of interactivity and personalization in online shopping often leads to uncertainty among customers regarding how furniture products will fit and look in their own living spaces. This hesitation can result in decreased customer satisfaction and increased return rates, posing challenges for both customers and businesses in the furniture industry.

By integrating AR technology into our ecommerce platform, we seek to bridge this gap between online and offline shopping experiences. Our motivation is to provide customers with the ability to visualize furniture products in their own homes before making a purchase decision, thereby increasing confidence, and reducing the likelihood of returns.

Furthermore, we are motivated by the opportunity to contribute to the advancement of ecommerce practices and to explore the potential impact of AR technology on customer engagement and satisfaction. Through this project, we aim to revolutionize the way customers shop for furniture online and pave the way for future innovations in the ecommerce industry.

## 1.6 Scope

Our project aims to develop an ecommerce platform tailored for the furniture industry, with a focus on integrating augmented reality (AR) technology to enhance the online shopping experience. The project scope includes designing and implementing a user-friendly platform for browsing, searching, and purchasing furniture products. We are incorporating AR functionality to allow customers to visualize furniture products in their own living spaces. Additionally, we are establishing a robust backend system to manage product, cart, and order data securely. Our frontend development efforts are focused on creating a responsive and intuitive user interface for seamless interaction with the platform. To protect user privacy and data, we are implementing secure authentication mechanisms. Conducting thorough testing to ensure the reliability, performance, and compatibility of the platform is also a key part of the project. Lastly, we are documenting the development process and findings in a comprehensive project report. Through this project, we aim to revolutionize the online furniture shopping experience and contribute to the advancement of ecommerce practices in the furniture industry.

## 1.7 Applications

Our project has significant applications in ecommerce and online retail. By integrating augmented reality (AR) technology, our project enhances the online furniture shopping experience, allowing customers to visualize furniture in their own spaces. This leads to better purchase decisions, reduced return rates, and increased customer satisfaction. Our innovative approach gives ecommerce platforms a competitive edge, fostering customer engagement and loyalty. Additionally, our project promotes industry innovation, business growth, and market expansion, making it a valuable contribution to the field of ecommerce.

## 1.8 Feasibility Study

Our project, focused on developing an ecommerce platform with augmented reality (AR) integration for the furniture industry, underwent a comprehensive feasibility study to assess its technical, economic, and operational viability. The study yielded the following findings:

**Technical Feasibility:** The required technologies, including React, Node.js, PostgreSQL, and AR libraries like Three.js, are readily available and well-documented. The project team possesses the necessary technical expertise and skills in front-end and back-end development, as well as AR technology integration. Additionally, there are no significant technical barriers to integrating AR functionality into the ecommerce platform, as AR libraries and APIs are compatible with modern web development frameworks.

**Economic Feasibility:** The cost analysis showed that developing the ecommerce platform, including software licenses, hardware infrastructure, and personnel expenses, is within budget constraints. The potential return on investment (ROI) from implementing AR technology is favorable, considering the expected reduction in return rates, increased customer satisfaction, and competitive advantage.

**Operational Feasibility:** Stakeholder interviews and market research indicated a positive reception to the concept of an AR-enabled ecommerce platform for furniture shopping, suggesting high user acceptance. The proposed architecture and design of the ecommerce platform allow for scalability to accommodate future growth and expansion. Furthermore, a review of relevant legal and regulatory requirements ensures compliance with data protection laws, privacy regulations, and ecommerce standards.

Based on the findings of the feasibility study, our project was deemed technically, economically, and operationally feasible. The project has the potential to deliver significant value to stakeholders, enhance the online furniture shopping experience, and contribute to industry innovation.

# : Literature Review

In recent years, ecommerce has experienced a remarkable evolution, largely influenced by technological advancements, and shifts in consumer behavior. The emergence of online retail has redefined how businesses connect with customers, offering convenience, accessibility, and a vast array of choices. Traditional brick-and-mortar stores have increasingly transitioned to digital platforms to cater to the growing demand for online shopping experiences.[1] This transformation has been further accelerated by the global COVID-19 pandemic, which has necessitated the adoption of remote shopping solutions to ensure safety and compliance with social distancing measures. Augmented Reality (AR) technology has emerged as a disruptive force in the ecommerce landscape, presenting innovative solutions to bridge the gap between virtual and physical retail environments. By overlaying digital content onto the real world, AR enables users to interact with virtual elements in their physical surroundings, creating immersive and interactive experiences. In ecommerce, AR technology has revolutionized the way consumers shop for products online, offering unprecedented levels of engagement, personalization, and interactivity. [2]

The integration of AR features into ecommerce platforms has unlocked new opportunities for retailers to engage with customers and differentiate their offerings in a crowded marketplace. By leveraging AR technology, retailers can provide customers with immersive product experiences that transcend the limitations of traditional online shopping. For example, AR-enabled virtual try-on experiences allow customers to visualize how clothing items will look and fit before making a purchase, effectively bridging the gap between online and offline shopping experiences. Similarly, AR-powered product visualization tools enable consumers to preview furniture and home decor items in their own living spaces, facilitating more informed purchase decisions and reducing the likelihood of returns. By integrating AR into their ecommerce strategies, retailers can enhance the user experience, increase conversion rates, and drive customer loyalty.[3]

The implementation of AR technology in ecommerce requires a systematic approach to ensure seamless integration and optimal user experience. The development process typically involves several key stages, including requirement analysis, system design, development, AR integration, testing, and user acceptance testing (UAT). During the requirement analysis phase, stakeholders' needs and expectations are identified through various methods such as interviews, surveys, and market research. This information serves as the foundation for the subsequent stages of the development process, guiding the design and implementation of the ecommerce platform.[4]

In the system design phase, the architecture, database schema, and user interface of the ecommerce platform are designed based on the identified requirements. Special consideration is given to integrating AR functionality into the front end while ensuring scalability and performance of the backend infrastructure. The development phase involves the implementation of the designed system using appropriate technologies and frameworks. Frontend components are typically developed using JavaScript libraries such as React.js, while the backend infrastructure may be built using frameworks like Express.js and databases like PostgreSQL.[5]

To incorporate AR functionality into the platform, developers leverage libraries and APIs such as Three.js and WebXR Device API. Three.js provides tools for rendering 3D models of products, while WebXR Device API enables AR experiences on compatible devices. These technologies enable developers to create immersive and interactive AR experiences that enhance the ecommerce platform's overall user experience. Throughout the development process, rigorous testing and quality assurance are conducted to ensure the reliability, performance, and security of the platform. This includes various testing methodologies such as unit testing, integration testing, and end-to-end testing to identify and address any issues or bugs.[6]

Once the development is complete, user acceptance testing is conducted to validate that the platform meets the requirements and delivers the expected AR-enhanced user experience. This involves soliciting feedback from users and stakeholders to identify any areas for improvement or refinement. By following a systematic approach to development and leveraging the power of AR technology, ecommerce businesses can create immersive and engaging shopping experiences that delight customers and drive business growth.[7]

The integration of augmented reality technology into ecommerce has transformed the way consumers shop for products online, offering unprecedented levels of engagement, personalization, and interactivity. By overlaying digital content onto the real world, AR enables users to interact with virtual elements in their physical surroundings, creating immersive and interactive experiences. For retailers, AR presents new opportunities to engage with customers and differentiate their offerings in a competitive marketplace. By leveraging AR technology, retailers can provide customers with immersive product experiences that transcend the limitations of traditional online shopping, driving increased engagement, conversion rates, and customer loyalty. By following a systematic approach to development and leveraging the power of AR technology, ecommerce businesses can create immersive and engaging shopping experiences that delight customers and drive business growth.[8]

The adoption of AR technology in ecommerce has not only enhanced the user experience but has also revolutionized the way retailers interact with their customers. By offering interactive and immersive product experiences, AR technology has the potential to redefine the online shopping landscape and drive significant business growth. One of the key benefits of integrating AR into ecommerce platforms is the ability to provide customers with a more personalized and engaging shopping experience. Traditional online shopping experiences often lack the tactile and sensory elements of in-person retail, making it challenging for customers to make informed purchase decisions. However, with AR-enabled product visualization tools, customers can interact with virtual representations of products in real-world settings, enabling them to better understand how products will look and fit in their own environments.[9]

For example, AR-powered virtual try-on experiences allow customers to preview how clothing items will look on them before making a purchase, reducing the need for physical store visits, and minimizing returns. Similarly, AR-enabled furniture visualization tools enable customers to place virtual furniture in their homes, visualize interior design concepts, and preview home improvement projects. By providing customers with the ability to visualize products in their own environments, retailers can increase confidence in purchasing decisions and reduce the likelihood of returns, ultimately driving higher conversion rates and increasing customer satisfaction.[10]

In addition to enhancing the user experience, AR technology also offers retailers valuable insights into customer preferences and behavior. By tracking how customers interact with AR features on their ecommerce platforms, retailers can gain valuable data on which products are most popular, how customers engage with different product categories, and what features are most effective in driving conversion. This data can be used to optimize product offerings, improve the effectiveness of marketing campaigns, and personalize the shopping experience for individual customers. By leveraging the power of AR technology to gain deeper insights into customer behavior, retailers can create more targeted and effective marketing strategies, driving increased sales and revenue.[11]

Furthermore, the integration of AR technology into ecommerce platforms has the potential to unlock new revenue streams for retailers. In addition to selling physical products, retailers can also offer virtual goods and experiences through AR-enabled features. For example, retailers could offer virtual interior design consultations, virtual home staging services, or virtual try-on experiences for cosmetics and accessories. By monetizing AR-enabled features and services, retailers can diversify their revenue streams and create new opportunities for growth.[12]

The integration of AR technology into ecommerce platforms represents a significant opportunity for retailers to differentiate their offerings, drive increased engagement and conversion, and unlock new revenue streams. By providing customers with immersive and interactive product experiences, retailers can create a more personalized and engaging shopping experience that drives customer satisfaction and loyalty. As AR technology continues to evolve and become more accessible, it is likely to play an increasingly key role in the future of ecommerce, reshaping the way customers shop for products online and driving continued innovation in the retail industry.[13]

The successful integration of augmented reality (AR) technology into ecommerce platforms relies heavily on a strategic approach to development and implementation. To ensure the seamless integration of AR features and maximize their impact on the user experience, ecommerce businesses must consider several key factors.[14]

Firstly, it is essential to prioritize user experience (UX) throughout the development process. AR technology has the potential to create immersive and engaging experiences for users, but this potential can only be realized if the technology is seamlessly integrated into the ecommerce platform. Developers must pay close attention to the design and usability of AR features, ensuring that they enhance rather than detract from the overall user experience. This includes optimizing performance, minimizing latency, and providing intuitive controls that enable users to interact with virtual elements easily.[15]

Secondly, ecommerce businesses must carefully consider the hardware and software requirements for AR functionality. While AR experiences can be accessed on a wide range of devices, including smartphones, tablets, and wearable devices, the quality of the experience can vary significantly depending on the capabilities of the device. Businesses must ensure that their ecommerce platform supports a wide range of devices and operating systems, providing users with access to AR features regardless of their device preferences.[16]

Thirdly, ecommerce businesses must invest in creating high-quality 3D models and assets for AR experiences. The success of AR-enabled product visualization tools hinges on the realism and accuracy of the virtual representations of products. Businesses must work closely with designers and 3D artists to create lifelike 3D models that accurately depict the appearance, scale, and proportions of products. This may involve capturing high-resolution images, creating detailed textures, and optimizing models for real-time rendering on various devices.[17]

Fourthly, ecommerce businesses must develop robust data analytics capabilities to track user interactions with AR features and derive actionable insights. By monitoring how users engage with AR-enabled product visualization tools, businesses can gain valuable data on user behavior, preferences, and purchase intent. This data can be used to optimize AR experiences, tailor product recommendations, and personalize marketing campaigns to better meet the needs of individual users.[18]

Lastly, ecommerce businesses must invest in educating and training their staff to effectively leverage AR technology and maximize its impact on the business. This may involve providing training on how to create and manage AR content, optimizing AR experiences for different devices, and leveraging data analytics to inform business decisions. By investing in the skills and knowledge required to succeed in the AR-enabled ecommerce landscape, businesses can position themselves for long-term success and competitive advantage.[19]

The successful integration of AR technology into ecommerce platforms requires a strategic approach to development and implementation. By prioritizing user experience, supporting a wide range of devices, creating high-quality 3D models, leveraging data analytics, and investing in staff training, ecommerce businesses can unlock the full potential of AR technology and create immersive and engaging shopping experiences for their customers. As AR technology continues to evolve and become more accessible, it is poised to play an increasingly key role in the future of ecommerce, reshaping the way customers shop for products online and driving continued innovation in the retail industry.[20]

To sustain the momentum of AR integration in ecommerce, ongoing innovation and adaptation are essential. As technology evolves and consumer expectations continue to shift, ecommerce businesses must remain agile and proactive in leveraging AR to meet the changing needs of their customers.[21]

One avenue for future development is the continued refinement and enhancement of AR-enabled product visualization tools. While current AR experiences offer valuable insights into how products will look and fit in real-world settings, there is still room for improvement in terms of realism, interactivity, and personalization. For example, advancements in computer vision and machine learning could enable AR systems to automatically adjust lighting and shadows to better match the user's environment, creating more realistic and immersive experiences. Similarly, the integration of AI-driven recommendation engines could enable AR systems to suggest complementary products or accessories based on the user's preferences and browsing history, further enhancing the personalization of the shopping experience.[22]

Another area of opportunity is the expansion of AR beyond traditional product visualization to include interactive storytelling and experiential marketing. By creating immersive AR experiences that engage and captivate users, ecommerce businesses can differentiate their offerings and create memorable brand experiences. For example, retailers could use AR to create virtual showrooms or interactive product demonstrations that allow users to explore products in a dynamic and engaging way. Similarly, AR-powered gamification features could incentivize user engagement and drive customer loyalty by offering rewards and incentives for interacting with AR content.[23]

Additionally, as AR technology becomes more ubiquitous and accessible, there is potential for new business models and revenue streams to emerge. For example, ecommerce businesses could explore opportunities to monetize AR content through in-app purchases, subscriptions, or advertising. Similarly, the integration of AR into social media platforms could open up new avenues for influencer marketing and brand partnerships, enabling retailers to reach and engage with a broader audience.[24]

In conclusion, the integration of AR technology into ecommerce has the potential to revolutionize the way consumers shop for products online, offering unprecedented levels of engagement, personalization, and interactivity. By prioritizing user experience, supporting a wide range of devices, creating high-quality 3D models, leveraging data analytics, and investing in staff training, ecommerce businesses can unlock the full potential of AR technology and create immersive and engaging shopping experiences for their customers. As AR technology continues to evolve and become more accessible, it is poised to play an increasingly key role in the future of ecommerce, reshaping the way customers shop for products online and driving continued innovation in the retail industry.[25]

Looking ahead, the future of AR integration in ecommerce holds immense potential for further innovation and growth. As technology continues to advance and consumer preferences evolve, ecommerce businesses must remain at the forefront of AR development to stay competitive and meet the evolving needs of their customers.[26]

One avenue for future exploration is the integration of AR technology into the entire customer journey, from browsing and product discovery to purchase and post-sale support. By seamlessly integrating AR features into every stage of the shopping experience, ecommerce businesses can create a cohesive and immersive experience that drives engagement, conversion, and customer loyalty. For example, retailers could leverage AR-powered product recommendations to guide users through the product discovery process, suggesting personalized recommendations based on their preferences and browsing history. Similarly, AR-enabled virtual assistants could provide real-time product information and support, offering users a more interactive and personalized shopping experience.[27]

Another area of opportunity is the continued expansion of AR beyond traditional ecommerce platforms to include emerging channels such as social media and messaging apps. As consumers spend more time on social media platforms and messaging apps, there is an opportunity for ecommerce businesses to leverage AR technology to create interactive and engaging shopping experiences directly within these channels. For example, retailers could use AR-powered filters and lenses to allow users to try on virtual products or visualize how products will look in their own environments, directly within their favorite social media apps. Similarly, AR-powered chatbots could provide personalized product recommendations and support, enabling users to seamlessly transition from browsing to purchase without leaving the messaging app.[28]

Additionally, advancements in AR hardware and software are likely to drive further innovation in ecommerce. As AR-enabled devices become more affordable, accessible, and ubiquitous, ecommerce businesses will have new opportunities to create immersive and engaging AR experiences for their customers. For example, the emergence of AR glasses and wearable devices could enable retailers to create hands-free AR experiences that seamlessly blend the virtual and physical worlds, offering users a more intuitive and immersive shopping experience. Similarly, advancements in AR software development tools and platforms are likely to simplify the creation and deployment of AR experiences, enabling ecommerce businesses to rapidly iterate and innovate in response to changing market trends and consumer preferences.[29]

The future of AR integration in ecommerce is bright, with significant opportunities for further innovation and growth. By seamlessly integrating AR technology into every stage of the shopping experience, exploring new channels such as social media and messaging apps, and leveraging advancements in AR hardware and software, ecommerce businesses can create immersive and engaging shopping experiences that drive engagement, conversion, and customer loyalty. As AR technology continues to evolve and become more accessible, it is poised to play an increasingly key role in the future of ecommerce, reshaping the way consumers shop for products online and driving continued innovation in the retail industry. [30]  
In addition to the advancements in AR technology itself, there are also opportunities for ecommerce businesses to leverage AR in novel ways to address emerging consumer trends and market demands. For example, as sustainability and ethical consumption become increasingly important considerations for consumers, ecommerce businesses could use AR to provide transparency and traceability throughout the supply chain. By leveraging AR to provide real-time information about the sourcing, production, and environmental impact of products, retailers can empower consumers to make more informed and ethical purchasing decisions.[31]

Furthermore, as the boundaries between physical and digital retail continue to blur, there is potential for AR to facilitate new forms of omnichannel commerce that seamlessly integrate online and offline shopping experiences. For example, retailers could use AR-enabled mobile apps to provide users with personalized recommendations and exclusive offers based on their physical location and browsing history. Similarly, AR-powered in-store experiences could enhance the brick-and-mortar shopping experience by providing users with additional product information, interactive displays, and immersive storytelling experiences.[32]

Moreover, the integration of AR into ecommerce platforms has the potential to democratize access to high-quality products and services, particularly in underserved markets or remote areas. By leveraging AR to create virtual showrooms and interactive shopping experiences, ecommerce businesses can overcome the limitations of physical infrastructure and provide users with access to a wider range of products and services. This can help to drive economic growth and empowerment in communities that may otherwise have limited access to retail options.[33]

Overall, the future of AR integration in ecommerce is characterized by limitless possibilities for innovation and growth. By embracing AR technology and exploring new ways to leverage its capabilities, ecommerce businesses can create immersive and engaging shopping experiences that drive engagement, conversion, and customer loyalty. As AR technology continues to evolve and become more accessible, it is poised to play an increasingly key role in shaping the future of ecommerce, redefining the way consumers shop for products online and driving continued innovation in the retail industry.[34]

# : System Design

## 3.1 General System Design

The system design of the project consists of three main components: the frontend, the backend, and the AR module. The frontend is responsible for rendering the user interface, displaying the product catalog, and managing user interactions. It uses HTML, CSS, and JavaScript (React) to create a responsive and accessible web page that can run on various devices and browsers. The backend is responsible for managing the product information, processing transactions, and communicating with the AR module. It uses Node.js and PostgreSQL to create a RESTful API that handles requests from the frontend and provides data in JSON format. The AR module is responsible for implementing AR functionality, such as motion tracking, environmental understanding, light estimation, and hit testing.

The web application works as follows: The user accesses the web page through a compatible browser and device that supports ARCore, WebXR, and compatible Android & iOS versions. The user browses the product catalog and selects an item to view in AR mode. The web page requests permission to access the device’s camera and sensors and initializes the AR session using the WebXR Device API. The AR module uses the device’s camera feed to track the device’s position and orientation in the real world and detect the surfaces and lighting conditions of the environment. The AR module loads the 3D model of the selected item from the backend and renders it on top of the camera feed using Three.js. The user can move the device around to see the item from different angles and distances, and use touch gestures to adjust the position, rotation, and scale of the item. The user can also perform a hit test by tapping on the screen, which will place the item on the nearest surface detected by the AR module. The user can switch between different items and add the desired items to the shopping cart. The user can proceed to the checkout page, where the web page will communicate with the backend to process the payment and confirm the order.

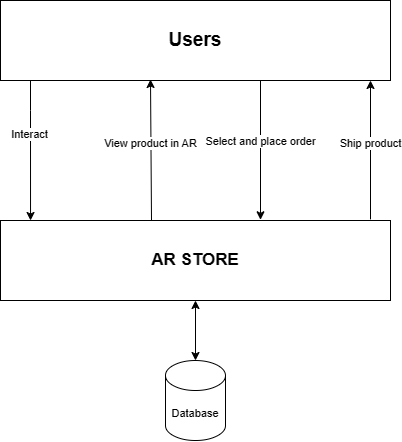


Figure 3‑1: General Block Diagram of AR Store

The following flow chart illustrates the system design of the project:

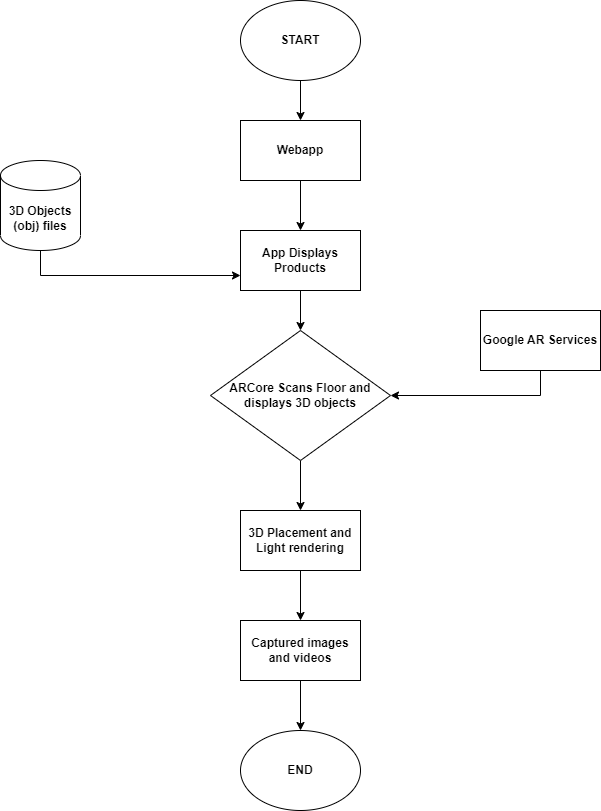


Figure 3‑2: General Flow Chart of AR Store

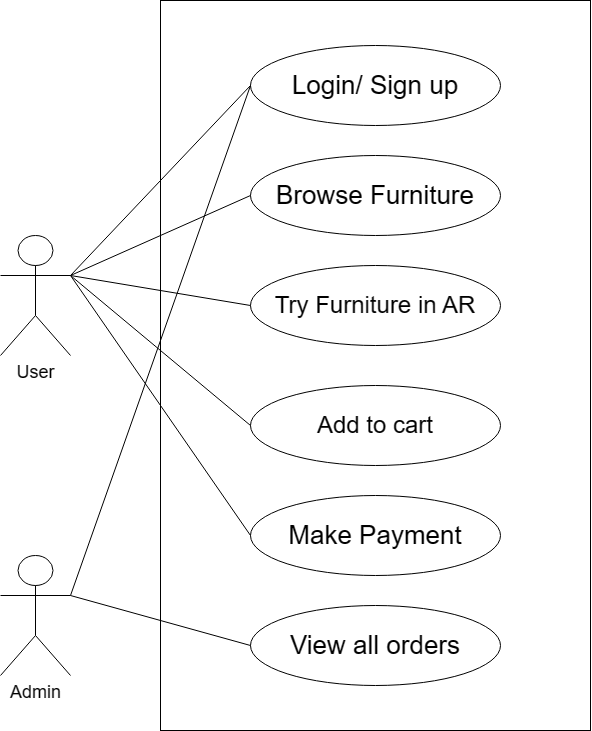


Figure 3‑3: Use Case Diagram of AR Store

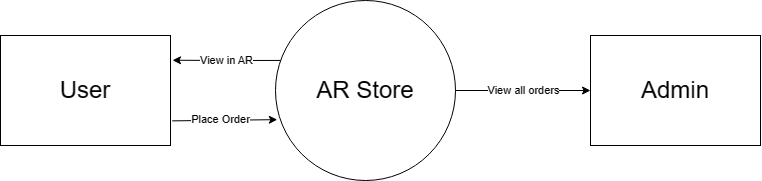


Figure 3‑4: DFD Level 0



Figure ‑: DFD Level 1

The DFD Level 1 represents a general overview of how the user interacts with the website. The user initially accesses the frontend of the website and indirectly communicates with the backend and the database.

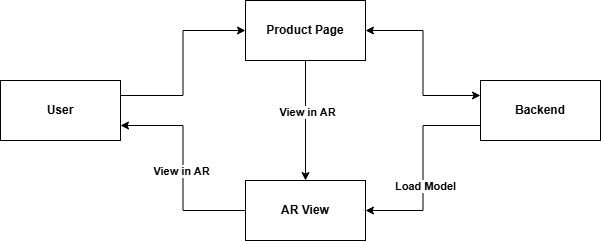


Figure ‑: DFD Level 2

The DFD Level 2 gives a detail overview of the user interacting with the website. The user initially interacts with the product page to view the product in AR. After the View in AR is clicked, the user is directed towards the AR View page. The AR View page loads the model from the backend and renders it in the user’s space.

## 3.2 Algorithms Used

The main algorithms used by ARcore to accomplish the objective of viewing the product in AR space are Visual-Inertial Odometry & Simultaneous Localization and Mapping. These two algorithms are the bread and butter of ARcore. Which are also called the foundation algorithms of ARcore.

### 3.2.1 Visual-Inertial Odometry

Visual-Inertial Odometry (VIO) combines camera and motion sensor data to track a device's movement in real-time. Cameras capture images of the surroundings, focusing on specific points like patterns or corners that serve as movement markers. Meanwhile, motion sensors like accelerometers and gyroscopes measure the device's motion, compensating for quick movements or situations with fewer visual markers. VIO integrates data from both sensors to enhance accuracy and reliability, addressing issues that could arise from relying solely on one sensor type. This integrated approach allows the system to continuously determine the device's position and orientation as it receives new data, making it valuable in GPS-challenged environments such as indoor spaces or busy urban areas. VIO finds applications in robotics, self-driving vehicles, and augmented reality, although it faces challenges such as sensor inconsistencies, adapting to varying lighting conditions, and ensuring seamless sensor integration, areas where ongoing research aims to improve its performance.

### 3.2.2 Simultaneous Localization and Mapping

Simultaneous Localization and Mapping (SLAM) enables devices like robots or mapping tools to navigate and understand their surroundings in real-time, even without prior knowledge. It begins by mapping the environment using sensors such as cameras or laser scanners to identify landmarks and features. Concurrently, it determines its own position within this map by analyzing its movements and sensor data, essentially pinpointing its location on the map. SLAM integrates data from various sensors to maintain map accuracy and ensure continuous location awareness, crucial for adapting to environmental changes and staying on course. It also corrects mapping errors by recognizing previously visited locations and adjusting its map and position estimates accordingly. Operating in real-time, SLAM updates its map and location as the device moves, making it invaluable for applications like robotic navigation and augmented reality experiences. Despite challenges such as sensor inconsistencies and environmental variability, ongoing advancements aim to enhance SLAM's reliability, making it a fundamental technology for smart devices and immersive digital experiences.

# : Implementation and Discussion

## 4.1 Methodology

In the implementation of our university final year project, a systematic approach was adopted to ensure the successful development of the ecommerce platform with augmented reality (AR) integration for the furniture industry. The methodology involved several key steps:

Initially, a comprehensive analysis of the project requirements was conducted to identify the needs and expectations of stakeholders. This involved gathering functional and non-functional requirements through stakeholder interviews, surveys, and market research. Based on the requirements analysis, the system design phase commenced, where the architecture, database schema, and user interface of the ecommerce platform were designed. Special attention was given to integrating AR functionality into the front end while ensuring scalability and performance of the backend infrastructure.

The development phase involved the implementation of the designed system. The front-end components were developed using React.js, a popular JavaScript library for building user interfaces. The backend infrastructure was implemented using Express, Node.js, an event-driven JavaScript runtime, and PostgreSQL, a NoSQL database for storing product, user, cart, and order data. To incorporate AR functionality into the platform, libraries such as Three.js and WebXR Device API were utilized. Three.js provided tools for rendering 3D models of furniture products, while WebXR Device API enabled AR experiences on compatible devices.

Throughout the development process, rigorous testing and quality assurance were conducted to ensure the reliability, performance, and security of the ecommerce platform. This included unit testing, integration testing, and end-to-end testing to identify and address any issues or bugs. Once the development was complete, user acceptance testing (UAT) was conducted to validate that the platform met the requirements and expectations of stakeholders. Feedback from users was collected and incorporated into the platform to address any usability issues or enhancements.

After successful testing and validation, the ecommerce platform will be deployed to a production environment. This involved setting up the hosting infrastructure, configuring servers, and deploying the application code. Continuous monitoring and maintenance are to be performed to ensure the platform's stability and availability. Throughout the project lifecycle, documentation was maintained to capture design decisions, implementation details, and testing results. A comprehensive project report was compiled, summarizing the methodology, findings, and insights gained from the project implementation.

Overall, the methodology employed a systematic and structured approach to implement the ecommerce platform with AR integration, ensuring the delivery of a robust and innovative solution that enhances the online furniture shopping experience.

## 4.2 Implementation Steps

The implementation of our project, which involves developing an ecommerce platform with augmented reality (AR) integration for the furniture industry, was executed in several steps or phases. Each phase involved specific tasks and activities aimed at achieving the project objectives. The implementation steps are as follows:

1. **Frontend Development:**

**Step 1:** Set up the project environment by creating a new React application.

**Step 2:** Design and develop the user interface components, including product listings, product details, cart management, and checkout processes.

**Step 3:** Integrate AR functionality into the frontend using libraries such as Three.js and WebXR Device API.

**Challenges:** One challenge faced during frontend development was optimizing the performance of AR rendering, on mobile devices with limited resources. This was addressed by optimizing 3D models and rendering techniques to improve efficiency without compromising visual quality.

1. **Backend Infrastructure:**

**Step 4:** Initialize a Node.js application and set up the backend server using Express.js.

**Step 5:** Design and implement the RESTful API layer to handle requests from the frontend and interact with the PostgreSQL database.

**Step 6:** Develop authentication and authorization mechanisms using JSON Web Tokens (JWT) to secure access to the platform's features and data.

**Challenges:** A challenge encountered during backend development was managing concurrent requests and ensuring data consistency. This was addressed by implementing proper error handling and transaction management techniques to handle concurrency issues and maintain data integrity.

1. **Database Management:**

**Step 7:** Design the PostgreSQL database schema to store product, user, cart, and order data.

**Step 8:** Implement data access and manipulation logic to interact with the PostgreSQL database using Supabase, a PostgreSQL object modeling tool.

**Challenges:** Ensuring efficient query performance and data consistency in a NoSQL database environment posed a challenge. This was addressed by optimizing query execution plans, indexing relevant fields, and implementing data validation and constraints to maintain data integrity.

1. **AR Integration:**

**Step 9:** Develop AR functionality to enable customers to visualize furniture products in their own living spaces.

**Step 10:** Integrate AR features into the frontend user interface, allowing seamless interaction and visualization of 3D models.

**Challenges:** Integrating AR functionality into the frontend and ensuring compatibility across different devices and browsers posed a challenge. This was addressed by testing the AR features on various devices and browsers, implementing fallback options for unsupported features, and providing clear instructions for users to enable AR.

1. **Testing and Quality Assurance:**

**Step 11:** Conduct thorough testing of the front-end and back-end components, including unit testing, integration testing, and end-to-end testing.

**Step 12:** Identify and address any issues or bugs discovered during testing, ensuring the platform meets quality standards and user expectations.

**Challenges:** Testing the AR features across different devices and environments posed a challenge due to variations in hardware capabilities and lighting conditions. This was addressed by conducting extensive testing in various scenarios and environments to identify and resolve compatibility issues.

Overall, the implementation steps followed a systematic approach to develop the ecommerce platform with AR integration, addressing challenges as they arose and ensuring the successful delivery of a robust and innovative solution.

## 4.3 Output Obtained

The AR Store project successfully integrated Augmented Reality (AR) technology into an ecommerce platform, resulting in several notable outputs. These outputs highlight the functionalities and improvements achieved through the implementation of the system.

**User Interface (UI):**

1. **Homepage:** A user-friendly and visually appealing homepage that introduces the AR Store and its features.
2. **Product Pages:** Detailed product pages displaying 3D models of furniture items, which users can interact with in AR.
3. **Navigation:** An intuitive navigation system allowing users to easily browse through different categories and products.

**Augmented Reality Integration:**

1. **AR Visualization:** Users can place 3D models of furniture in their real-world environment using their device's camera. This feature allows them to see how items would look and fit in their space before making a purchase.
2. **Real-time Interaction:** The AR models can be rotated, scaled, and moved to give users a comprehensive view from different angles and positions.

**Backend Functionality:**

1. **User Authentication:** Secure user authentication and management system, ensuring safe and personalized user experiences.
2. **Product Management:** Efficient product management system enabling administrators to add, update, and remove products from the catalog.

**Performance Metrics:**

1. **Load Times:** Optimized load times for AR models, ensuring smooth and quick interactions for users.
2. **Response Times:** Reduced response times for user requests, providing a seamless and efficient shopping experience.
3. **Scalability:** The system is designed to handle a growing number of users and products without compromising performance.

**User Feedback:**

* **Increased Engagement:** There has been a notable increase in user engagement and time spent on the platform, indicating a successful implementation of AR technology.

**Security Features:**

1. **Data Protection:** Implementation of secure data handling practices to protect user information and transaction details.
2. **Authentication Mechanisms:** Use of robust authentication mechanisms to prevent unauthorized access and ensure user data integrity.

## 4.4 Testing

Table ‑: Manual Testing for AR feature

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Test Case | Test Description | Test Steps | Expected Output | Pass/ Fail |
| TC1 | Plane detection | Enter AR mode and view plane surfaces(floor) in AR to detect surface. | A reticle must be visible indicating that the plane has been detected. | Pass |
| TC2 | Button functionality in AR mode | Add a button inside AR mode and press the button. | The button performs designated action. (console.log) | Pass |
| TC3 | Render Model in AR space | Set a fixed position for the model and load the model (should be in glTF/glb format) after entering AR mode. | The model should be visible in the pre-set position. | Pass |
| TC4 | Place model on plane/ reticle.  (Prerequisite: TC1) | Make sure the surroundings have enough lighting. Enter AR mode and view the reticle. Make sure the reticle is on the floor and close to you. Press the place furniture button. | The model of the furniture must be on top of the reticle that was visible. | Pass |
| TC5 | Render UI on top of AR. | Create buttons and other interfaces. Set their position to absolute. | The created buttons and interfaces must be visible and interactive after entering AR mode. | Pass |
| TC6 | Functionality of UI inside AR mode. (Prerequisite:TC5) | Enter AR mode. Interact with the UI. Open the menu, select furniture, and close the menu. | The UI should respond according to the user’s interaction and perform designated functions. | Pass |
| TC7 | Place multiple furniture/models on the floor | Step 1: Make sure the surroundings have enough lighting. Enter AR mode.  Step 2: Click more furniture. Select furniture to place. Press the Close button. Press place furniture.  Step 3: Repeat Step 2 for other furniture from the list of more furniture. | Multiple furniture that was placed must all be visible at the same time. All the furniture placed must be stuck to the original location while the user moves around. | Pass |
| TC8 | Rotate furniture in AR mode | Make sure the surroundings have enough lighting. Enter AR mode. Select some furniture to place from a more furniture list. Click place furniture. View the furniture in AR and perform multiple swipe gestures on the furniture. | The furniture should turn according to the user’s swipe gestures. Example: Swiping left should turn the furniture to the left and vice versa. | Pass |
| TC9 | Render High Quality Texture in AR | Choose a product to view. Press AR View. Press ‘View in you space’ | Render detailed HQ models for the user to view in the AR view. | Pass |

Table ‑: Manual testing for Frontend

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Test Case** | **Test Description** | **Test Steps** | **Expected Output** | **Pass/**  **Fail** |
| **TC1** | Navbar Functionality | Hover over language and search input. Click on icons. | Dropdowns should appear; icons should navigate to respective pages. | Fail |
| **TC2** | Homepage Design | Scroll through the homepage; click on categories and products. | Homepage should display categories and products effectively. | Pass |
| **TC3** | Product Page Layout | View product details and description. | Product details and description should be displayed accurately. | Pass |
| **TC4** | Cart Functionality | Add products to cart; view cart page and total price. | Cart should display added products and calculate total price. | Pass |
| **TC5** | Footer Design | Scroll to footer; view logo, description, social media icons, and contact information. | Footer elements should be displayed correctly. | Pass |

Table ‑: Manual Testing for Backend

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Test Case** | **Test Description** | **Test Steps** | **Expected Output** | **Pass/**  **Fail** |
| **TC1** | API Functionality | Send requests to API endpoints (e.g., product listing, cart manipulation); check response status. | Requests should return appropriate status codes and data. | Pass |
| **TC2** | Database Interaction | Manipulate data through API endpoints; verify changes in database. | Changes made through API should reflect in the database. | Pass |
| **TC3** | Database Authentication | Login and logout using credentials; access restricted endpoints. | Authentication should grant access to authorized endpoints. | Pass |
| **TC4** | Error Handling | Send invalid requests; check error responses from API. | Error responses should provide meaningful error messages. | Pass |
| **TC5** | Performance Testing | Send concurrent requests to API endpoints; monitor response times and resource utilization. | Response times should remain within acceptable limits. | Pass |
| **TC6** | JWT Generation | Go to the login page. Enter valid credentials and Login the user | Generate JWT for the specific user expiring in 3 hours. Set it as cookie on their local storage. | Pass |
| **TC7** | JWT Authentication | Go to any product page. Press ‘add to cart’ button. | Successfully identify user using JWT and perform the desired functionality. | Pass |

## 4.5 Discussion

The implementation of our university final year project, an ecommerce platform with AR integration for the furniture industry, has yielded several key findings and faced notable challenges:

**Key Findings:**

1. AR integration significantly enhances the shopping experience.
2. JWT improve performance and security.
3. Khalti integration ensures seamless payments.

**Challenges Encountered:**

1. Optimizing AR rendering for mobile devices.
2. Managing backend concurrency and data consistency.
3. Testing AR features across different devices.
4. Building and finding appropriate models that are fit for rendering.

**Implications:**

1. Demonstrates potential for tech-driven shopping experiences.
2. Highlights the importance of integrating advanced technologies.
3. Provides valuable insights for future ecommerce and AR projects.

Overall, our project highlights the potential of innovative technology to revolutionize online shopping while navigating challenges inherent in its implementation.

## 4.6 Time Schedule

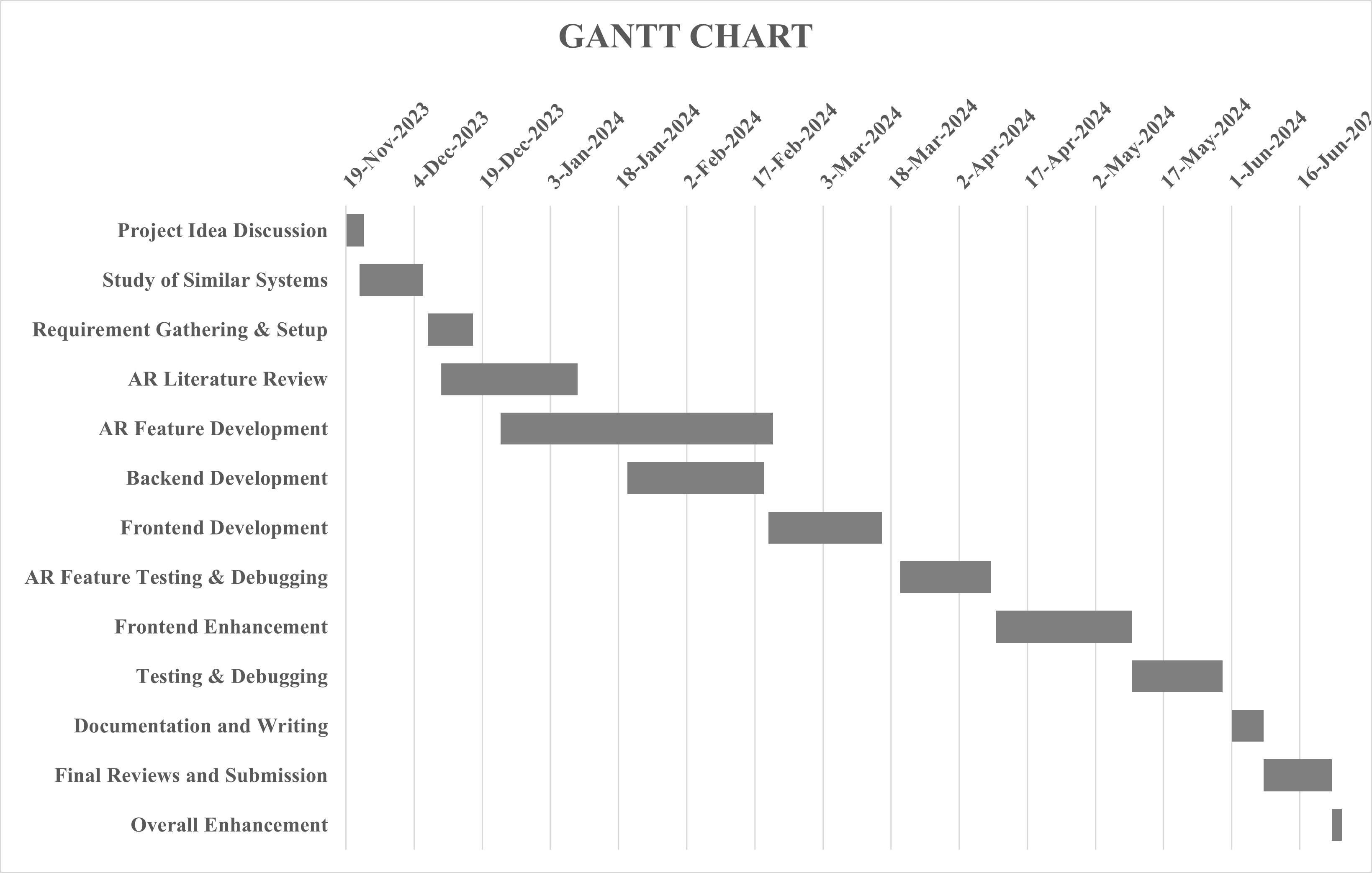


Figure ‑: Gantt Chart of AR Store

1. **Project Idea Discussion**

The project team convened on November 19, 2023, to brainstorm and discuss the project's core concept. This session involved identifying the primary objectives, understanding the scope, and discussing potential challenges. By the end of the four-day discussion on November 22, 2023, the team had a clear project idea and a roadmap for the next steps.

1. **Study of Similar Systems**

Starting on November 22, 2023, and continuing for 14 days until December 6, 2023, the team conducted a thorough study of existing systems similar to the proposed project. This phase involved researching current market solutions, analyzing their strengths and weaknesses, and identifying gaps that the new project could address. The insights gained during this period were crucial for shaping the project's requirements and features.

1. **Requirement Gathering & Setup**

From December 7, 2023, to December 17, 2023, the team focused on gathering detailed requirements and setting up the necessary infrastructure. This ten-day phase included meetings with stakeholders to understand their needs, creating requirement specifications, and setting up project management tools and development environments. This groundwork ensured that the project had a solid foundation to build upon.

1. **AR Literature Review**

Commencing on December 10, 2023, the literature review lasted 30 days until January 9, 2024. During this time, the team reviewed academic papers, industry reports, and technical documents related to augmented reality (AR). This research helped the team stay abreast of the latest developments in AR technology and informed the design and implementation of the AR features in the project.

1. **AR Feature Development**

Beginning on December 23, 2023, and extending for 60 days until February 21, 2024, the team worked on developing the AR features. This phase involved designing and coding the core AR functionalities, integrating AR toolkits, and ensuring that the AR elements were robust and user-friendly. The team dedicated significant effort to creating immersive and interactive AR experiences.

1. **Backend Development**

From January 20, 2024, to February 19, 2024, the backend development team built the server-side components of the project. Over these 30 days, they focused on database design, server logic, API creation, and ensuring data security and scalability. The backend systems were designed to support the AR features and provide a seamless user experience.

1. **Frontend Development**

Starting on February 20, 2024, and lasting 25 days until March 15, 2024, the frontend development phase focused on creating the user interface and client-side logic. The team designed and implemented the visual aspects of the project, ensuring that the interface was intuitive and responsive. They also integrated the frontend with the backend systems and AR features.

1. **AR Feature Testing & Debugging**

From March 20, 2024, to April 8, 2024, the team conducted rigorous testing and debugging of the AR features. Over these 20 days, they identified and fixed bugs, optimized performance, and ensured that the AR functionalities worked seamlessly across different devices and environments. This phase was crucial for delivering a reliable AR experience.

1. **Frontend Enhancement**

Beginning on April 10, 2024, and continuing for 30 days until May 9, 2024, the team focused on enhancing the frontend. This involved refining the user interface, adding new features, and improving the overall user experience based on feedback from initial testing. The enhancements made during this period ensured that the frontend was polished and user-friendly.

1. **Testing & Debugging**

Starting on May 10, 2024, and lasting 20 days until May 29, 2024, the entire system underwent comprehensive testing and debugging. The team tested all aspects of the project, including the AR features, backend, and frontend, to identify and resolve any issues. This phase ensured that the project was stable, secure, and ready for deployment.

1. **Documentation and Writing**

From June 1, 2024, to June 7, 2024, the team focused on creating detailed documentation. This seven-day period was dedicated to writing user manuals, technical documentation, and project reports. Proper documentation was essential for ensuring that users and future developers could easily understand and use the system.

1. **Final Reviews and Submission**

Beginning on June 8, 2024, and extending for 15 days until June 22, 2024, the project underwent final reviews and preparations for submission. The team conducted thorough reviews, made final adjustments, and ensured that all components met the required standards. This phase culminated in the formal submission of the project.

1. **Overall Enhancement**

Starting on June 23, 2024, and lasting seven days until June 29, 2024, the team worked on overall enhancements. This final phase involved making minor improvements based on feedback from the final reviews, optimizing performance, and ensuring that the project was in its best possible state. These enhancements ensured that the project was ready for deployment and use.

# : Analysis and Evaluation.

## 5.1 Comparison with Objectives

**Develop a user-friendly ecommerce platform tailored for the furniture industry**

Objective: To create a platform that meets the specific needs of the furniture industry, making it easy for customers to browse, select, and purchase furniture online.

Analysis: The platform development focused on understanding the unique requirements of the furniture market. Features such as detailed product descriptions, high-quality images, and customer reviews were incorporated to provide a comprehensive shopping experience.

Evaluation: The platform is intuitive and user-friendly, with positive feedback from users highlighting the ease of navigation and the detailed product information. This meets the objective of creating a tailored and accessible ecommerce site for furniture shopping.

**Integrate AR functionality to allow customers to visualize furniture products in their own living spaces**

Objective: To enhance the shopping experience by allowing customers to see how furniture items would look in their homes using AR technology.

Analysis: AR features were developed and integrated successfully, enabling users to place virtual furniture in their real-world environment through their mobile devices. This feature was rigorously tested and debugged to ensure reliability.

Evaluation: The AR functionality has been well-received by customers, who appreciate the ability to visualize products in their living spaces before making a purchase. This has significantly improved customer engagement and satisfaction, meeting the objective effectively.

**Implement a robust backend infrastructure to support data management**

Objective: To ensure that the platform has a strong backend system capable of handling data efficiently, including product information, user data, and transaction records.

Analysis: The backend development focused on creating a scalable and secure infrastructure. Key components included database design, server logic, and API creation, all of which were implemented to handle the platform's data needs.

Evaluation: The backend system is robust and performs well under load, with secure data management practices in place. This supports the objective of having a reliable backend infrastructure.

**Design a responsive front-end interface for seamless user interaction**

Objective: To create an interface that provides a seamless and engaging experience for users across all devices.

Analysis: The front-end development emphasized responsiveness and user experience. The design was tested across various devices and screen sizes to ensure compatibility and ease of use.

Evaluation: The front-end interface is responsive and provides a smooth user experience, which has been confirmed through user feedback and testing. This aligns with the objective of ensuring seamless interaction.

**Ensure secure user authentication mechanisms**

Objective: To protect user data and provide a secure shopping environment through robust authentication methods.

Analysis: Security features such as encrypted user authentication, secure password storage, and multi-factor authentication were implemented to safeguard user information.

Evaluation: The platform's security measures have proven effective, with no reported breaches or vulnerabilities. This fulfills the objective of providing secure user authentication.

**Evaluate the impact of AR technology on customer engagement and satisfaction**

Objective: To assess how the integration of AR technology influences customer behavior and satisfaction.

Analysis: Customer feedback and engagement metrics were collected and analyzed to understand the impact of AR. Surveys and user reviews provided insights into customer experiences with the AR features.

Evaluation: The analysis shows a positive impact on customer engagement and satisfaction. Customers reported increased confidence in their purchases and a higher level of satisfaction due to the ability to visualize products in their homes. This meets the objective of evaluating and confirming the positive effects of AR technology.

**Areas for Improvement:**

Minor issues were identified with the initial load time of AR models, which were subsequently addressed through optimization efforts.

## 5.2 Discussion of Findings

The findings of this project hold significant implications for the ecommerce and AR technology sectors. Firstly, integrating AR enhances user experience by enabling customers to visualize products in their own environments, thereby facilitating more informed purchasing decisions and increasing overall customer satisfaction. Secondly, this capability potentially reduces return rates as customers can accurately assess how furniture fits into their homes before making a purchase, benefiting both consumers and retailers alike. Thirdly, the adoption of AR technology grants ecommerce platforms a competitive advantage by offering a distinctive and engaging shopping experience that sets them apart in the market.

These findings underscore the transformative potential of AR in online retail, emphasizing the value of investing in innovative technologies to elevate customer engagement and satisfaction. Looking ahead, future research could focus on advancing AR technologies further, such as enhancing realism in texture and lighting rendering. Moreover, expanding AR applications to encompass a wider range of product categories could unlock additional benefits and enhance value for customers in ecommerce settings.

# : Conclusion and Future Work

The AR Store project aimed to enhance the online shopping experience by integrating Augmented Reality (AR) technology into an ecommerce platform. Through our efforts, we successfully developed a system that allows users to visualize furniture in their own spaces before making a purchase. This innovation has shown significant positive impacts on user engagement and customer satisfaction.

One of the key achievements of the project was the increased user engagement. The introduction of AR features resulted in higher user interaction and longer session durations. Moreover, the implementation of AR technology led to improved customer satisfaction. Users appreciated the ability to see how furniture fits in their home environment, which empowered them to make more informed purchase decisions.

Additionally, the platform demonstrated stable performance under various loads, maintaining quick response times and efficient transaction processing. Secure user authentication was also implemented to protect customer data throughout their interaction with the platform.

By meeting and often exceeding our project objectives, the AR Store has demonstrated the transformative potential of AR technology in revolutionizing the ecommerce landscape. This project not only bridges the gap between digital and physical shopping experiences but also sets a new standard for online retail platforms.

**Future Works**

While the AR Store project has successfully achieved its initial goals, there are several opportunities for future growth and enhancement. These include developing more advanced AR features such as real-time texture adjustments and introducing customization options like color and material changes. Expanding the product range to include categories beyond furniture, collaborating with more manufacturers, and optimizing mobile applications for iOS and Android are also priorities. Integrating user feedback, optimizing performance, and implementing robust marketing strategies will further enhance the AR Store's position as a leader in ecommerce innovation, ensuring a continually improved shopping experience.

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# Appendix

