

Mobile Augmented Reality Service Performance for Interactive Product Visualization and Purchase Confidence

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ABSTRACT

The rapid advancement of mobile technology has significantly transformed digital commerce by creating more interactive, immersive, and user centered shopping experiences. Nevertheless, conventional mobile commerce applications still face challenges in delivering realistic product visualization, causing uncertainty among consumers during purchasing decisions. **Augmented Reality (AR)** technology has emerged as an innovative solution that enables users to interact with virtual products within real-world environments through mobile devices. This study aims to develop and evaluate a Mobile Augmented Reality Application for Interactive Product Visualization in order to enhance user experience, product understanding, and consumer confidence in mobile commerce platforms. The research employed a **quantitative experimental** approach through the design and implementation of an AR-based mobile application using **Unity and ARCore technologies**. Data collection was conducted through usability testing and questionnaire distribution involving users familiar with mobile shopping applications. The evaluation process focused on **usability, interactivity, visualization quality**, and user satisfaction. The results indicate that the implementation of AR technology product visualization accuracy, user engagement, and purchase confidence compared to conventional mobile interfaces. Furthermore, users perceived the application as more effective in supporting product exploration and reducing uncertainty before purchasing. This study also contributes to the achievement of the Sustainable Development Goals (SDGs), particularly **SDG 9 (Industry, Innovation, and Infrastructure)** by encouraging innovation in digital commerce technologies, and SDG 12 (Responsible Consumption and Production) by promoting informed purchasing decisions and may potentially contribute to reducing product returns. In conclusion, mobile AR applications demonstrate substantial potential to improve digital shopping experiences while supporting sustainable technological innovation within the mobile commerce ecosystem.

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1. INTRODUCTION

The proliferation of smartphones and high-speed mobile internet has accelerated the transition toward mobile commerce as a dominant digital shopping platform. Consumers increasingly rely on mobile applications for product discovery, evaluation, and purchasing, creating greater demand for shopping experiences that are both functionally efficient and perceptually meaningful [1]. Despite the rapid growth of mobile commerce, conventional platforms still rely on two-dimensional images, textual descriptions, and short videos that inadequately represent product characteristics such as size, texture, proportion, and environmental fit. This limitation creates perceptual uncertainty, reducing consumer confidence and purchase intention while increasing the likelihood of product returns [2]. To address these limitations, Augmented Reality (AR) enables virtual products to be visualized within real-world environments through real-time interaction and three dimensional registration [3].

In mobile commerce, AR allows consumers to examine products from different perspectives, manipulate their position and scale, and evaluate their suitability within actual environments, providing a more immersive and informative pre-purchase experience than conventional visualization methods [4]. Previous studies demonstrate that AR enhances consumer engagement, satisfaction, and purchase intention in digital commerce [5]. However, most research focuses on technology adoption and consumer perception, while limited attention has been given to the development and empirical evaluation of complete Mobile AR systems integrated with sustainable development objectives. This study therefore addresses these identified gaps by developing and evaluating a Mobile Augmented Reality Application for Interactive Product Visualization within a mobile commerce environment.

The proposed application is constructed using Unity and ARCore frameworks, incorporating core interactive AR functionalities including real-time plane detection, three dimensional object placement, rotation, and scaling to enable spatially accurate product evaluation on Android devices. The system is assessed through structured usability testing and user experience evaluation involving users with prior mobile commerce experience, with the objective of determining the extent to which mobile AR technology enhances product visualization quality, user engagement, and purchase confidence relative to conventional interfaces [6]. Beyond its technical contribution, this study supports SDG 9 by strengthening digital commerce innovation and SDG 12 by encouraging more informed purchasing decisions that may reduce consumer uncertainty and unnecessary product returns. Accordingly, the proposed Mobile AR application contributes to sustainable digital transformation within the mobile commerce ecosystem [7].

Despite the growing body of research investigating Augmented Reality in digital commerce, most existing studies primarily emphasize technology acceptance, consumer perception, or conceptual discussions regarding the potential benefits of AR. Comparatively fewer studies have presented the complete development, implementation, and empirical evaluation of a fully functional Mobile Augmented Reality application that integrates real-time product visualization with usability assessment and sustainable development objectives [8]. Moreover, previous research rarely combines technical implementation using Unity and ARCore with comprehensive evaluation dimensions, including usability, interaction quality, visualization quality, and purchase confidence within a single experimental framework. Therefore, this study addresses these research gaps by proposing and empirically evaluating a practical Mobile Augmented Reality application for interactive product visualization [9]. The primary novelty of this research lies in the integration of real world AR system implementation, standardized usability evaluation through the System Usability Scale (SUS), multidimensional user experience assessment, and explicit alignment with SDG 9 and SDG 12, thereby providing both technological and practical contributions to the advancement of sustainable mobile commerce [10].

Compared with previous AR commerce studies, which primarily emphasize technology acceptance, consumer perception, or conceptual discussions of AR adoption, this study provides a more comprehensive contribution by integrating the complete development and empirical evaluation of a functional Mobile Augmented Reality application [11]. Unlike earlier research, the proposed system combines real-time implementation using Unity and ARCore, standardized usability evaluation through the System Usability Scale (SUS), multidimensional assessment of interaction quality, product visualization quality, user satisfaction, and purchase confidence, while explicitly linking these outcomes to SDG 9 and SDG 12. This integrated approach distinguishes the proposed application from prior studies and strengthens its originality by demonstrating both technical feasibility and practical value for sustainable mobile commerce.

2. LITERATURE REVIEW

This section presents the theoretical and empirical foundation underlying this research. The review synthesizes key concepts and prior findings related to mobile applications, Augmented Reality technology, interactive product visualization, User Experience in Mobile Commerce.s and the Sustainable Development Goals (SDGs) as the sustainability framework of this study. The discussion is organized to establish a coherent theoretical basis that contextualizes the research objectives and justifies the methodological decisions undertaken in this investigation [12].

Recent studies have further demonstrated the growing role of Mobile Augmented Reality in digital commerce by improving customer engagement, purchase intention, perceived usefulness, and decision quality through immersive visualization technologies [13]. Contemporary research also highlights that advances in mobile computing, artificial intelligence, and real-time rendering have significantly enhanced the usability, responsiveness, and scalability of AR-based shopping applications. These developments indicate that Mobile AR has evolved from an experimental visualization technology into a practical digital commerce solution capable of supporting customer centered innovation and sustainable retail transformation [14].

2.1. Mobile Application

Mobile applications represent software systems specifically engineered to operate on smart devices such as smartphones and tablets, leveraging the computational capabilities and sensor-rich environments of modern mobile hardware [15]. The exponential growth of mobile computing infrastructure over the past decade has significantly expanded the scope and sophistication of digital services delivered through mobile platforms, encompassing communication, education, healthcare, entertainment, and commerce [16]. In the domain of digital commerce specifically, mobile applications have evolved from simple product catalogues into complex, feature rich platforms that support real-time transactions, personalized recommendations, and multimedia product experiences through internet connected devices.

Contemporary mobile application development extends beyond functional performance to prioritize interactive user experiences, system responsiveness, and seamless integration with emerging technologies. Modern mobile platforms increasingly incorporate artificial intelligence, cloud computing, Internet of Things (IoT), and Augmented Reality (AR) capabilities to elevate service quality and deepen user engagement [17]. Within mobile commerce environments, application quality plays a pivotal role in shaping user trust, satisfaction, and purchasing behavior, as consumers evaluate applications not only on their transactional efficiency but also on the richness and intuitiveness of the experience they deliver [18].

2.2. Augmented Reality Technology

Augmented Reality (AR) is an interactive technology that overlays virtual objects and digital information onto real world environments in real time through the mediation of digital devices such as smartphones, tablets, and wearable displays. The foundational definition provided by [19] characterizes AR systems by three essential properties the combination of real and virtual elements, real time interactivity, and accurate three dimensional registration of virtual objects within physical space [20]. This tripartite definition distinguishes AR from related immersive technologies such as Virtual Reality (VR), which replaces the physical environment entirely with a simulated one, and Mixed Reality (MR), which encompasses a broader spectrum of real virtual integration. AR's unique capacity to enhance rather than replace physical reality makes it particularly well suited for commerce applications, where maintaining awareness of real world spatial context is essential for effective product evaluation [21]. The technical advancement of mobile AR has been substantially driven by the development of dedicated software development kits, most notably ARCore (Google) and ARKit (Apple), which provide the computational infrastructure necessary for stable and responsive AR experiences on consumer mobile devices [22].

In digital commerce contexts, AR technology addresses a fundamental limitation of online retail by enabling consumers to interact with virtual product representations prior to purchase. Users can rotate, resize, and spatially position three dimensional product models within their actual surroundings, thereby gaining a more accurate and diagnostically valuable understanding of product characteristics than static two-dimensional images can provide [23]. This interactive visualization capability has been shown to significantly reduce the perceptual gap between consumer expectations and actual product experience, contributing to improved purchase confidence and reduced post purchase dissatisfaction. As mobile hardware continues to advance and AR frameworks become increasingly sophisticated, AR is progressively recognized as a foundational technology for the next generation of mobile commerce interfaces [24].

2.3. Interactive Product Visualization

Interactive product visualization refers to the dynamic digital presentation of products that enables users to explore, manipulate, and evaluate product representations in a spatially accurate and perceptually realistic manner [25]. In digital commerce environments, product visualization serves as a critical mediating factor between consumer decision-making and purchase behavior, given that online consumers are unable to physically inspect products prior to purchase. The quality and realism of product visualization directly influence consumer confidence, perceived product diagnosticity, and ultimately purchase intention [26].

The integration of AR technology into product visualization systems fundamentally transforms this dynamic by enabling the creation of three dimensional, spatially registered, and interactively manipulable product experiences. Through AR-based visualization, consumers can observe products from any desired perspective, assess their proportional relationship to real-world objects, and evaluate their visual compatibility within specific environmental contexts capabilities that closely approximate the sensory richness of in-store product examination. Empirical research has consistently demonstrated that immersive and interactive visualization positively influences purchase intention, consumer satisfaction, and trust in online retail contexts [27].

2.4. User Experience in Mobile Commerce

User Experience (UX) is a multidimensional construct encompassing the perceptions, emotional responses, cognitive assessments, and behavioral outcomes generated through a user's interaction with a digital system or application. In mobile commerce environments, UX has emerged as one of the most consequential determinants of application success, directly influencing usability, user engagement, consumer trust, and purchasing behavior. A consistently positive user experience fosters customer loyalty, encourages repeated platform engagement, and strengthens the overall competitive positioning of mobile commerce applications within an increasingly saturated digital marketplace.

The incorporation of AR technology introduces a qualitatively distinct dimension of user interaction within mobile commerce systems. AR-based interfaces provide immersive, experiential shopping encounters that differ substantially from conventional two-dimensional mobile interfaces, engaging users through real-time spatial interaction and multi perspective product exploration. This enhanced interactivity has been empirically associated with elevated perceived enjoyment, stronger emotional engagement with products, and increased willingness to adopt AR-enabled platforms for future shopping activities. User experience is commonly evaluated using SUS, TAM, and UEQ to assess usability, technology acceptance, and interaction quality.

2.5. Sustainable Development Goals (SDGs)

This research is directly associated with two specific SDGs that frame its sustainability contribution. The first is SDG 9 (Industry, Innovation, and Infrastructure), which emphasizes the importance of building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation as drivers of economic development and human well being [28]. The development of a mobile AR application for interactive product visualization represents a concrete instantiation of digital innovation within commercial infrastructure, advancing the sophistication and interactivity of mobile commerce platforms while contributing to the modernization of digital service delivery systems [29]. By demonstrating the practical viability of AR-based commerce technology, this study supports broader efforts to strengthen innovation ecosystems within the digital economy.

The second relevant goal is SDG 12 (Responsible Consumption and Production), which promotes sustainable consumption patterns, resource efficiency, and the reduction of waste across production and consumption systems [30]. AR-based interactive product visualization directly supports this goal by empowering consumers to make more accurate, informed, and deliberate purchasing decisions prior to transaction completion. When consumers can realistically evaluate product characteristics including size, appearance, and spatial suitability within their own environments before purchasing, the likelihood of post purchase dissatisfaction and subsequent product returns is substantially reduced [31]. This reduction in return rates carries meaningful environmental and economic implications, contributing to more sustainable patterns of consumption and minimizing the resource waste associated with reverse logistics processes [32].

3. METHODOLOGY

This study adopts a quantitative usability evaluation with a single-group post-test design, to develop and evaluate a Mobile Augmented Reality Application for Interactive Product Visualization. The quantita-

tive orientation enables systematic measurement of user responses across four evaluated dimensions usability, interaction quality, product visualization quality, and purchase confidence. The experimental dimension involves controlled real environment testing of the implemented AR system to empirically assess its functional performance and user acceptance under conditions approximating authentic mobile commerce usage.

3.1. Research Design and Variables

The study employs a single-group post-test experimental design, in which participants interact with the developed AR application and subsequently provide structured evaluative responses through validated instruments. System development follows the Multimedia Development Life Cycle (MDLC) framework, comprising six sequential stages concept, design, material collection, assembly, testing, and distribution. The application was constructed using Unity (version 2021.3 LTS) and the Google ARCore SDK, incorporating core AR functionalities including plane detection, three dimensional object placement, real-time rotation and scaling via touch gesture input, and ambient light estimation for physically accurate object rendering.

The independent variable is the Mobile AR Application, defined by its interactive AR features. The dependent variables are usability, measured via the System Usability Scale (SUS), interaction quality, product visualization quality, and purchase confidence, each measured through a researcher developed Likert scale instrument.

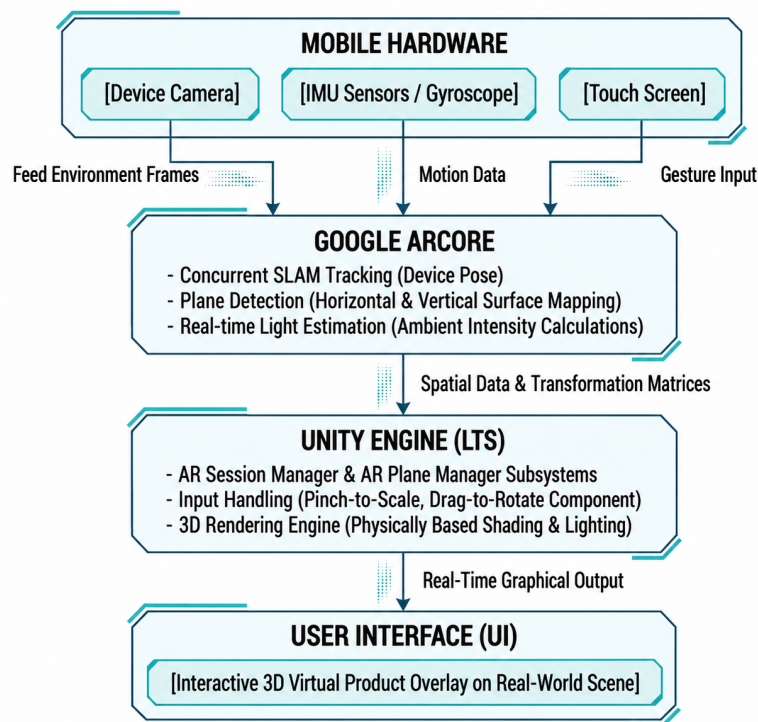


Figure 1. System Architecture of the Mobile Augmented Reality Product Visualization Application

As illustrated in Figure 1, the Mobile AR application employs a layered architecture that integrates smartphone hardware with real-time digital rendering. Google ARCore processes data from the RGB camera, accelerometer, and gyroscope to perform simultaneous localization and mapping (SLAM), detect environmental surfaces, estimate device position, and analyze lighting conditions [33, 34]. The resulting spatial information is transmitted to the Unity Engine, which loads and anchors three-dimensional product models onto detected surfaces, applies real-time lighting, and manages user interactions such as scaling, rotation, and repositioning. The rendering engine continuously updates the virtual object according to camera movement, allowing users to interactively visualize products within their physical environment in real time [35].

Before the usability evaluation, the application underwent functional and technical testing on ARCore-compatible Android smartphones equipped with rear cameras, inertial sensors, and sufficient processing capabilities. Testing was conducted under controlled indoor conditions with adequate lighting and textured flat surfaces to verify plane detection, object placement, scaling, rotation, repositioning, light estimation, tracking

stability, rendering continuity, gesture performance, and overall system responsiveness [36]. This preliminary evaluation confirmed that the core AR components operated consistently and reliably, thereby supporting the practical feasibility of the proposed Mobile AR application before its usability and user experience assessment.

3.2. Data Types and Sources

This study utilizes two types of data to support the development and evaluation of the proposed Mobile Augmented Reality application. Primary data were obtained through structured usability testing, the System Usability Scale (SUS) questionnaire, and supplementary five-point Likert scale questionnaires assessing interaction quality, product visualization quality, user satisfaction, and purchase confidence. The evaluation instruments were administered after participants completed predefined product exploration tasks using the developed AR application.

Secondary data were obtained from peer-reviewed journal articles, conference proceedings, books, and official technical documentation related to Unity and Google ARCore [37]. These sources provided the theoretical and technical foundation for application development, instrument construction, and interpretation of the evaluation results.

3.3. Participants

Forty participants were recruited through purposive sampling based on criteria relevant to the study objectives. Participants were required to be aged between 18 and 35 years, own an ARCore-compatible Android smartphone, use mobile commerce applications at least once per month, and possess adequate visual and motor abilities for touch-based interaction [38]. Individuals with professional experience in AR development or formal usability and UX evaluation were excluded to minimize technical expertise bias and better represent typical end users.

The sample size was determined based on usability evaluation guidelines suggesting that 20–50 participants are generally sufficient to identify major usability issues and produce reliable measures of user satisfaction and perceived usability [39]. All participants voluntarily participated and provided written informed consent before the evaluation sessions. All participants provided written informed consent prior to participation.

Table 1. Demographic Characteristics and Mobile Commerce Experience of Participants ($N = 40$)

Demographic Metric	Classification Category	Frequency (n)	Percentage (%)
Gender	Male	18	45.0%
	Female	22	55.0%
Age Group (Years)	18–24	25	62.5%
	25–30	11	27.5%
	31–35	4	10.0%
Primary Occupation	Student / College Student	21	52.5%
	Private Sector / Civil Servant	14	35.0%
	Entrepreneur / Others	5	12.5%
Mobile Commerce Frequency / Month	1–2 Times	19	47.5%
	3–5 Times	15	37.5%
	>5 Times	6	15.0%

Table 1 outlines the demographic profiling of the 40 participants recruited through purposive sampling for the usability evaluation. The sample exhibits a balanced gender distribution, comprising 55% female and 45% male respondents. The demographic is predominantly composed of young adults, with the 18–24 age bracket representing the largest segment (62.5%), which aligns with the tech-savvy student population (52.5%) who frequently adopt immersive technologies. Crucially, all participants met the mandatory threshold for mobile commerce familiarity, with 52.5% engaging in digital shopping transactions three or more times per month, thereby ensuring valid, expert-unbiased user experience feedback.

3.4. Data Collection and Instruments

Data collection employed three complementary techniques to achieve methodological triangulation. Structured observation documented participant interaction behaviors, task completion patterns, and usability difficulties during testing sessions using a standardized behavioral checklist. Usability testing required participants to complete standardized product exploration tasks engaging all core AR features, with task performance recorded for triangulation with self-report data. Questionnaire administration was conducted immediately following each session using two instruments sequentially.

The System Usability Scale (SUS) provided a standardized measure of overall perceived usability, yielding a composite score interpreted across industry-standard adjective ratings and grade scales. where scores of 78.9–100 correspond to "Good" to "Excellent" categories. The supplementary Likert scale questionnaire evaluated interaction quality, visualization quality, user satisfaction, and purchase confidence through items rated on a five-point scale. Prior to full-scale administration, the instrument underwent content validation by three HCI specialists and pilot testing with five participants. Internal consistency was confirmed through Cronbach's alpha ($\alpha \geq 0.70$), with an acceptance threshold of $\alpha \geq 0.70$.

3.5. Data Analysis

Quantitative data were analyzed using descriptive statistics, including mean score computation, frequency distribution, and percentage scoring. SUS scores were calculated using the standard algorithm and interpreted against Bangor et al.'s adjective rating scale. Likert scale responses were analyzed by computing mean scores per dimension, with scores of 4.00–5.00 interpreted as high to very high user agreement. Observation data were analyzed thematically and triangulated with questionnaire findings to produce a unified interpretation of usability and user experience quality. All computations were performed using Microsoft Excel and IBM SPSS Statistics version 25.

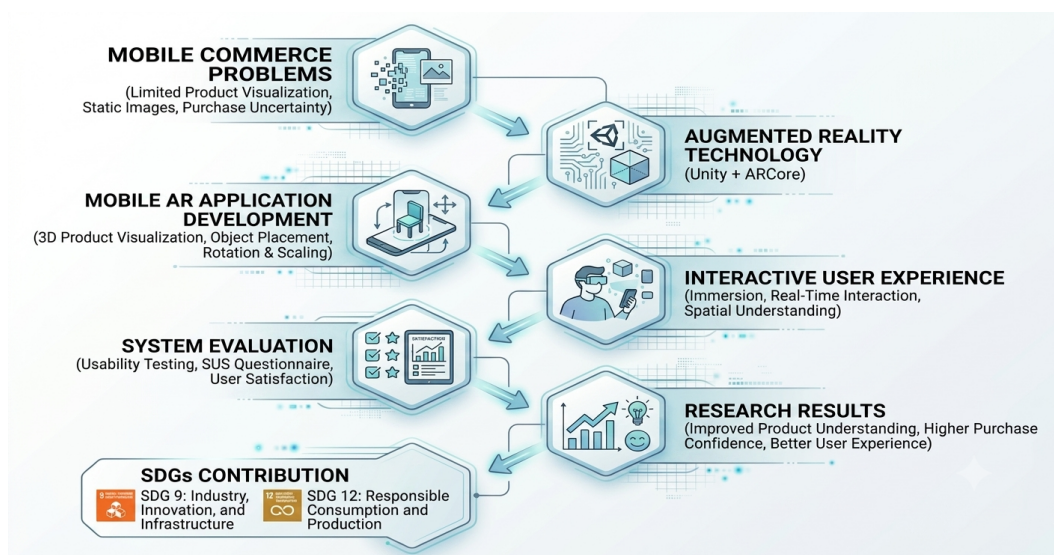


Figure 2. Research Framework of Mobile Augmented Reality Application for Interactive Product Visualization

Figure 2 illustrates the research framework of the proposed Mobile Augmented Reality application, starting from the identification of product visualization problems in conventional mobile commerce systems to the implementation of AR technology using Unity and ARCore. The framework highlights the development of interactive 3D product visualization features, system evaluation through usability and user experience assessments, and the resulting improvements in product understanding, purchase confidence, and user interaction. In addition, the framework demonstrates the contribution of the proposed system toward SDG 9 and SDG 12 through technological innovation and more responsible digital consumption.

4. RESULTS AND DISCUSSION

This section presents and discusses the findings derived from the system implementation, usability evaluation, and user experience assessment of the developed Mobile Augmented Reality Application for Interactive Product Visualization. The results are systematically organized across four key dimensions system implementation outcomes, usability and user experience performance, comparative discussion against prior empirical literature, and the contribution of findings toward sustainable development objectives. Each dimension is analyzed in relation to the established research objectives and contextualized within the broader body of AR and mobile commerce scholarship to substantiate the theoretical and practical significance of the reported outcomes.

4.1. System Implementation Results

The Mobile AR Application was successfully implemented using Unity (version 2021.3 LTS) and the Google ARCore SDK, delivering a fully functional interactive product visualization system on Android devices. The implemented system supports four core AR functionalities horizontal and vertical plane detection via SLAM-based motion tracking, three-dimensional object anchoring and environmental placement, multi-axis rotation and pinch-to-scale gesture interaction, and ambient light-responsive virtual object rendering for physically accurate illumination simulation. These functionalities collectively enable users to place, manipulate, and inspect virtual product models within their physical surroundings in real time, approximating the spatial and perceptual richness of physical product examination.

Performance evaluation across a range of ARCore-compatible Android devices confirmed stable and responsive application operation under adequate environmental conditions, particularly with respect to surface detection accuracy, tracking consistency, and rendering frame rate. Minor degradation in AR tracking stability was observed on entry-level devices with limited processing capability and lower-resolution camera sensors; however, these variations did not materially compromise overall interaction quality, task completion rates, or user experience outcomes. This finding is consistent with prior research indicating that mobile AR performance is substantially moderated by device hardware specifications and environmental factors, particularly ambient lighting intensity and surface texture complexity. The successful deployment and stable performance of the application across diverse device configurations confirms the technical viability of Unity and ARCore as a development platform for real-world mobile commerce AR applications.

The functional testing results confirmed that all core AR features were successfully implemented throughout the evaluation process. The application consistently supported plane detection, three-dimensional object placement, scaling, rotation, repositioning, and real-time light estimation during product visualization tasks. The integration of Unity and ARCore enabled stable interaction between virtual objects and the physical environment, allowing participants to complete all assigned product exploration tasks without functional failures. These findings demonstrate that the proposed Mobile AR application provides a reliable technical foundation for subsequent usability and user experience evaluation.

4.2. Usability and User Experience Evaluation

Usability assessment using the System Usability Scale (SUS) across 40 participants yielded a composite mean score of 82.5 out of 100, placing the application firmly within the "Good to Excellent" usability category according to the adjective rating Classification proposed by [40]. This result indicates strong and broad user acceptance of the developed AR system across the evaluated participant population. Supplementary Likert scale evaluation across the four user experience dimensions produced consistently high mean scores across all assessed aspects, as presented in Table 2.

Table 2. Evaluation Results of the Mobile Augmented Reality Application

Evaluation Aspect	Measurement Method	Mean Score	Category
Usability	System Usability Scale (SUS)	82.5 / 100	Good – Excellent
Interaction Quality	Likert Scale (1–5)	4.3	High
Product Visualization Quality	Likert Scale (1–5)	4.5	Very High
User Satisfaction	Likert Scale (1–5)	4.2	High
Purchase Confidence	Likert Scale (1–5)	4.4	High – Very High

Table 2 presents the quantitative evaluation results across five assessed dimensions. Overall, the results demonstrate consistently positive user responses, with all aspects achieving scores within the "High" to "Very High" categories. The evaluation results across all four Likert scale dimensions demonstrated consistently high scores.

Product visualization quality recorded the highest mean score ($M = 4.5$), confirming that AR-based three-dimensional rendering was perceived as spatially accurate and contextually informative. Purchase confidence ranked second ($M = 4.4$), reflecting that spatial product interaction meaningfully reduced perceptual uncertainty prior to purchasing decisions. Interaction quality ($M = 4.3$) confirmed that gesture-based object manipulation was perceived as responsive and natural, successfully balancing AR feature richness with interaction simplicity. User satisfaction recorded the lowest score among the evaluated dimensions ($M = 4.2$), although it remained within the "High" category, possibly because three-dimensional interaction requires greater cognitive effort than conventional mobile interfaces. Beyond demonstrating high usability, the evaluation results indicate that the proposed Mobile AR application has strong potential to accelerate user acceptance of immersive shopping technologies.

4.3. Discussion in Relation to Prior Literature

The evaluation findings reported in this study are broadly consistent with and extend the empirical evidence established by prior research in AR-based digital commerce. Research by [41], demonstrated that AR's distinctive media characteristics particularly its interactivity and representational vividness significantly enhance consumer engagement and behavioral responses in retail environments, a finding corroborated by the high interaction quality and visualization scores recorded in this study. Similarly, [42] reported that AR-augmented shopping experiences measurably improve customer satisfaction and purchase willingness relative to non-AR alternatives, consistent with the elevated purchase confidence and user satisfaction scores observed among participants in the present investigation.

The present findings are also consistent with more recent studies published between [42], and [43], which report that Mobile Augmented Reality enhances user engagement, shopping confidence, and purchase intention by providing realistic product visualization and intuitive interaction. These contemporary studies further demonstrate that improvements in AR frameworks, mobile hardware capabilities, and intelligent rendering technologies have accelerated the practical adoption of AR in digital commerce, supporting the results obtained in the present study.

This study extends these foundational findings by providing empirical evidence from a fully implemented mobile AR system evaluated under real-device testing conditions, rather than laboratory simulations or conceptual prototypes. The consistently high usability and user experience scores demonstrate that the advantages of Mobile Augmented Reality identified in previous studies can also be achieved in practical mobile commerce environments.

From a broader digital commerce perspective, these findings demonstrate that Mobile Augmented Reality contributes not only to improving individual user experience but also to enhancing business performance by facilitating more informed purchasing decisions. The combination of high usability, realistic product visualization, and increased purchase confidence may encourage higher customer engagement and strengthen consumers' willingness to adopt AR-enabled shopping platforms. These findings are consistent with previous empirical studies reporting that immersive visualization technologies positively influence consumer trust, purchase intention, and overall shopping experience, thereby reinforcing the practical value of integrating AR into modern mobile commerce ecosystems.

From a managerial perspective, the findings of this study provide practical guidance for multiple stakeholders within the digital commerce ecosystem. For e-commerce companies and retailers, the implementation of Mobile Augmented Reality can improve customer engagement, strengthen purchase confidence, and enhance product visualization, thereby supporting more informed purchasing decisions and reducing uncertainty during online shopping. For application developers, the findings demonstrate the importance of integrating accurate AR tracking, intuitive user interaction, and high-quality rendering to maximize user experience. Meanwhile, digital business decision makers may utilize the evaluation results as empirical evidence when planning investments in AR technologies, prioritizing customer centered digital innovation, and developing competitive mobile commerce strategies that enhance both business performance and long-term customer satisfaction.

4.4. Contribution to Sustainable Development Goals

The findings of this study carry meaningful and direct implications for two Sustainable Development Goals. With respect to SDG 9 (Industry, Innovation, and Infrastructure), the successful implementation and strongly positive user evaluation of the mobile AR application provide empirical validation of AR-driven technological innovation within mobile commerce infrastructure. The demonstrated technical feasibility and user acceptance of the system contribute to the body of evidence supporting AR as a practical and scalable digital commerce technology, thereby advancing the modernization of mobile retail infrastructure and strengthening innovation ecosystems within the digital economy.

The practical contribution to SDG 9 is further demonstrated through measurable system performance outcomes. The obtained usability and visualization results indicate that the proposed system not only introduces technological innovation but also strengthens digital commerce infrastructure. By providing an interactive, scalable, and user centered platform capable of supporting future smart retail ecosystems.

With respect to SDG 12 (Responsible Consumption and Production), the significant improvements in purchase confidence ($M = 4.4$) and product visualization quality ($M = 4.5$) observed in this study provide empirical support for the proposition that AR-based pre-purchase product evaluation meaningfully reduces consumer uncertainty and the likelihood of post purchase dissatisfaction. By enabling consumers to assess product characteristics including spatial dimensions, material appearance, and environmental compatibility within their actual surroundings prior to purchase, the proposed system supports more deliberate, accurate, and informed purchasing decisions.

Furthermore, the measurable evaluation results indicate that the proposed system contributes to responsible consumption by increasing users' purchase confidence. (Mean = 4.4) and enhancing product understanding before purchase. Although the present study did not directly measure return rates, these empirical findings provide practical evidence that Mobile AR technology can support more sustainable digital consumption practices and improve decision quality within mobile commerce environments.

This reduction in perceptual uncertainty may contribute to reducing return rates or could potentially reduce the incidence of expectation driven product returns, contributing to more sustainable consumption patterns and minimizing the logistical, economic, and environmental costs associated with reverse commerce operations.

4.5. Limitations

Despite the consistently positive findings, several methodological limitations warrant transparent acknowledgment. First, the sample was restricted to 40 participants recruited through purposive sampling within a single geographic and demographic context, which constrains the generalizability of findings to broader, more culturally and demographically diverse mobile commerce user populations. Second, the application was evaluated exclusively on Android devices due to ARCore framework dependency, leaving the usability, performance, and user experience characteristics of a potential iOS implementation unexamined. Third, usability testing was conducted within a controlled environment that may not fully replicate the variability of authentic real-world AR usage conditions, including inconsistent ambient lighting, cluttered or low-texture surfaces, and diverse device handling behaviors. Fourth, the single-group post-test design precludes direct empirical comparison between AR-based and conventional mobile commerce interfaces within the scope of this investigation, representing a significant opportunity for more rigorous comparative experimental research in future studies.

5. MANAGERIAL IMPLICATIONS

The findings of this study provide practical guidance for e-commerce companies, retailers, and mobile application developers seeking to enhance digital shopping experiences through Mobile Augmented Reality (AR). The high usability, product visualization quality, and purchase confidence achieved by the proposed application indicate that integrating AR into mobile commerce platforms can improve customer engagement, facilitate more informed purchasing decisions, and reduce uncertainty before purchase. To maximize these benefits, organizations should prioritize the implementation of stable AR tracking, intuitive user interaction, and high-quality 3D visualization when developing AR-enabled applications. By adopting these strategies, businesses can strengthen customer satisfaction, improve their competitive advantage in the digital marketplace, and support sustainable digital commerce through more responsible consumer purchasing behavior.

6. CONCLUSION

This study developed and evaluated a Mobile Augmented Reality application for interactive product visualization to improve digital shopping experiences within mobile commerce environments. The results demonstrate high usability (SUS = 82.5) together with positive evaluations of product visualization, interaction quality, user satisfaction, and purchase confidence. These findings indicate that Mobile Augmented Reality can effectively enhance users understanding of product characteristics, support more informed purchasing decisions, and strengthen customer engagement in digital commerce. This study contributes to mobile commerce by demonstrating the practical implementation of Unity and ARCore while supporting SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production). The findings also provide practical guidance for implementing user-centered AR technologies to improve customer experience and digital business competitiveness.

Furthermore, this study contributes to the broader development of smart systems and mobile computing by demonstrating the practical implementation of an for digital commerce. By integrating real-time AR interaction, user-centered usability evaluation, and sustainable innovation principles, the proposed system provides practical evidence of how emerging technologies can improve digital shopping experiences while supporting technology-driven infrastructure development (SDG 9) and promoting more responsible consumption practices (SDG 12). These contributions reinforce the relevance of this study to the fields of intelligent information systems, mobile computing, and digital commerce, while providing a practical reference for future smart commerce applications.

This study is limited by the relatively small sample size, Android-only implementation, and controlled testing environment. Future studies are encouraged to include larger and more diverse participant groups, evaluate cross-platform implementations, compare AR-based and conventional shopping interfaces through experimental designs, and investigate the integration of emerging technologies such as Artificial Intelligence, markerless AR, and advanced interaction techniques to further improve the effectiveness and scalability of mobile commerce applications.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: QA and TS; Methodology: QA and CA; Software: MF and TS; Validation: QA, TS, and CA; Formal Analysis: RN and MF; Investigation: CA and RN; Resources: QA; Data Curation: RN and MF; Writing Original Draft Preparation: CA and RN; Writing Review and Editing: QA and TS; Visualization: MF; All authors, QA, TS, CA, RN, and MF, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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The authors received no financial support for the research, authorship, and/or publication of this article.

7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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