



Markerless Tracking Based on User Defined Targets to Enhance User Experience in Android-Based Furniture Visualization Applications

Indra Wijaya ¹, Supriyanto ^{2,*}

¹ Informatics Department, Universitas Ahmad Dahlan, Indonesia

* Correspondence: supriyanto@tif.uad.ac.id

Citation: Wijaya, I.; Supriyanto, S. (2025). Markerless Tracking Based on User Defined Targets to Enhance User Experience in Android-Based Furniture Visualization Applications. JTIM: Jurnal Teknologi Informasi Dan Multimedia, 7(4), 731-743. <https://doi.org/10.35746/jtim.v7i4.731>

Received: 03-07-2025

Revised: 31-07-2025

Accepted: 11-08-2025



Copyright: © 2025 by the authors. This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License. (<https://creativecommons.org/licenses/by-sa/4.0/>).

Abstract: Furniture is essential for daily activities and enhances the aesthetic appeal of various environments, including residences, commercial establishments, and cafes. Traditionally, furniture retailers display their products through catalogs or brochures. However, such media often fail to provide a comprehensive view of the furniture, hindering prospective buyers from evaluating items from all angles or determining their suitability for a specific room. This study proposes developing an Android application for interior layout design. It addresses these challenges by employing Augmented Reality technology in conjunction with a Markerless User Defined Target technique. The utilization of markerless user-defined targets is particularly advantageous, as it eliminates the requirement for predefined physical markers. This simplifies the process for the user and offers greater flexibility compared to conventional marker-based approaches, representing a key novelty of this work. The resultant software features a product catalog and comprehensive product information. It also allows users to view 3D augmented reality items, as well as scale, rotate, and manipulate these objects within their environment. Two individuals verified the system's operation through functional testing employing the Blackbox methodology. Usability testing, using the System Usability Scale, yielded above-average ratings, categorizing the software as "acceptable." Further examinations of viewing distance and angle indicated that camera quality influences augmented reality range, with AR objects remaining visible at angles ranging from 90° to 40°. These evaluations indicate that the Markerless User Defined Target method is effective and suitable for AR-based interior furniture layout planning.

Keywords: augmented reality; markerless tracking; user defined target; usability testing

1. Introduction

Consumer expectations toward the shopping experience continue to evolve, with increasing demands for more personalized and immersive interactions. The furniture retail industry faces significant challenges in meeting these expectations through traditional marketing approaches, such as printed catalogs and showroom displays. The inability of consumers to accurately visualize furniture placement within their personal spaces considering variables such as size, color, style, and alignment with existing interior design creates a psychological barrier in the purchasing process. This uncertainty may lead to reduced purchase confidence, lower conversion rates, and overall diminished customer satisfaction. Consequently, a more adaptive and responsive visualization strategy is required to meet consumers' evolving needs.

Recent advancements in Augmented Reality (AR) technology offer a transformative solution to the visualization challenges faced by the furniture industry[1]. By enabling the real-time integration of virtual objects into physical environments, AR fosters significantly enhanced interactive and immersive experiences[2], [3]. The application of AR in furniture marketing holds substantial potential to revolutionize consumer engagement, minimize product return rates, and increase sales volumes. The urgency of this research is driven by shifting consumer behavior toward digital platforms, intensifying market competition, and the underutilization of AR in the furniture retail sector. Furthermore, modern consumers increasingly expect interactive and personalized shopping experiences expectations that are difficult to fulfill through conventional marketing methods[4].

Previous research has shown that AR can significantly enhance usability and user experience in retail contexts. Studies have highlighted that AR improves perceived usefulness, ease of use, and overall satisfaction[5], [6]. Markerless AR, in particular, eliminates the need for physical markers, allowing for more natural and flexible interaction with virtual objects[7], which contributes to a more intuitive interface and reduces barriers to technology adoption[8], [9]. These findings suggest that AR especially when implemented with markerless tracking can streamline user interaction and increase technology acceptance across diverse user groups[10].

In addition to usability improvements, AR with markerless tracking also plays a critical role in boosting customer engagement[11]. Research indicates that immersive AR experiences enhance consumer involvement and foster more favorable attitudes toward products and brands[12]. Markerless AR applications that allow users to simulate real-world product placements have been shown to improve purchasing confidence and reduce return rates[13], [14]. Furthermore, studies reveal that AR visualization contributes to stronger emotional connections with products, more effective product understanding, and increased intention to purchase[15], [16]. Other scholars have noted that a seamless AR experience can bridge the gap between online and offline retail environments, enhancing brand perception and reinforcing customer loyalty [17].

This study focuses on the development of a furniture promotion application that utilizes Augmented Reality technology with a Markerless User Defined Target methodology on the Android platform. This paper differs from prior work by explicitly leveraging a markerless approach, which offers substantial improvements in user experience by eliminating the need for physical markers, thereby enhancing the flexibility of virtual object placement and enabling more intuitive and natural interactions. This methodological innovation distinguishes the present study from prior research, which predominantly relied on marker-based tracking methods. Additionally, the proposed application has the potential to integrate with existing e-commerce platforms and can be enhanced with supporting features, such as personalized visual representations of furniture and lighting condition simulations. This research aims to contribute meaningfully to the advancement of AR applications within the furniture industry by offering an innovative solution to visualization and interaction challenges in contemporary marketing strategies.

2. Materials and Methods

2.1. Materials

The data acquisition phase involves the collection of relevant data that will be utilized throughout the development and evaluation of this research. Data collection was conducted on-site at DM Mebel, a local furniture store located in Yogyakarta, Indonesia. The selection of this store was based on its accessibility and availability of representative furniture items suitable for application testing.

For the purposes of this study, four distinct furniture products were selected from the store's catalog: a sofa, a bookshelf, a wardrobe, and a table. These items were chosen

to represent a variety of furniture types commonly used in residential interior layouts, allowing the application to demonstrate its capabilities in different spatial and contextual configurations. The selected products provide a practical basis for modeling, visualization, and interactive placement within the augmented reality environment.

The 3D models of these furniture items were created to closely resemble their real-world counterparts, ensuring that the visualization in the AR application is both accurate and realistic. These models were used during system implementation to simulate real-world placement in user environments. An overview of the four selected furniture items from DM Mebel is presented in Figure 1.



Figure 1. Interior objects sample.

2.2. Analysis

This phase aims to identify user requirements and the functional specifications necessary for the application. Data collection methods employed include:

- **Literature Review:** A comprehensive examination of previous research, scientific literature, and articles related to Augmented Reality (AR), Markerless User Defined Target (UDT) technology, interior layout planning, and user experience design.
- **Observation:** Direct observation of users engaged in real-world furniture layout planning activities, both manually and (where applicable) through the use of existing digital applications.
- **Interviews (Optional):** Semi-structured interviews conducted with potential users to gather deeper insights into their needs, preferences, and expectations regarding the application.

The findings from this analysis phase are documented as a set of functional and non-functional requirements, which serve as the foundation for the application's design.

2.3. Design

This phase encompasses the design of both the markerless tracking system architecture and the Android mobile application architecture. The markerless system architecture outlines how the application detects and tracks the environment without relying on physical markers. Architectural diagrams illustrate the following key components:

- **User Interface (UI):** The design of an intuitive and user-friendly interface to support seamless interaction.

- AR Module: The augmented reality module responsible for initializing AR sessions, detecting the physical environment, and placing virtual objects accurately.

2.4. Implementation

The implementation phase begins with the creation of 3D furniture models using Blender. Application logic—comprising user interactions, virtual object placement, and object manipulation—is implemented using Vuforia and Unity.

Prior to testing, it is essential to verify that the AR functionality meets specific spatial criteria. This study adopts a minimum angle visibility threshold of 40 degrees and a camera-to-target distance of 2 meters to ensure proper AR object rendering and usability during interaction.

2.5. Testing

Usability testing was conducted to evaluate the user experience of the developed application. The evaluation utilized the System Usability Scale (SUS) questionnaire. The target respondents included potential customers of household furniture stores. Participants completed the SUS questionnaire after interacting with the application, providing quantitative data for assessing perceived usability.

3. Results

3.1. 3D Modeling

The 3D modeling phase focused on constructing virtual representations of real-world furniture products from DM Mebel Yogyakarta. The modeling process was carried out using Blender, an open-source 3D graphics software widely used in digital content creation, animation, and game development. The objective was to replicate the geometry and coloration of the actual products as accurately as possible to ensure visual consistency between the physical items and their augmented reality counterparts.

The selected furniture items including a sofa, bookshelf, wardrobe, and table—were modeled based on their real dimensions, textures, and structural features. These specific items are considered the main products offered by the store. Color matching was also conducted to reflect the true appearance of each product, enhancing realism during AR visualization. To ensure proportional accuracy and computational efficiency, a modeling scale of 1:10 was adopted. This means that real-world measurements in centimeters were divided by 10, and the resulting values were applied as dimensions within the Blender workspace. This scaling approach enabled effective manipulation and visualization of the models in a virtual environment while maintaining the relative proportions of each item.

The complete modeling process involved creating base meshes, refining the geometry, applying material textures, and assigning accurate surface colors. These steps ensured that the final 3D models were both visually realistic and optimized for integration into the Unity and Vuforia-based AR system. An illustration of the 3D modeling item, including its rotation and the need to adjust the X, Y, Z dimensions and scales, is shown in Figure 2. When inspecting the transform properties of these models, you can observe: Location (the current position of the object in 3D space with X, Y, Z coordinates), Rotation (indicating if the object has any rotation applied, e.g., 0°, 0°, 0° for no rotation), Scale (how the object has been resized, possibly with non-uniform scaling like X=1.48, Y=1.24, Z=3.81), and Dimensions (the actual size of the object in Blender units, such as 2.96 x 2.48 x 7.62).

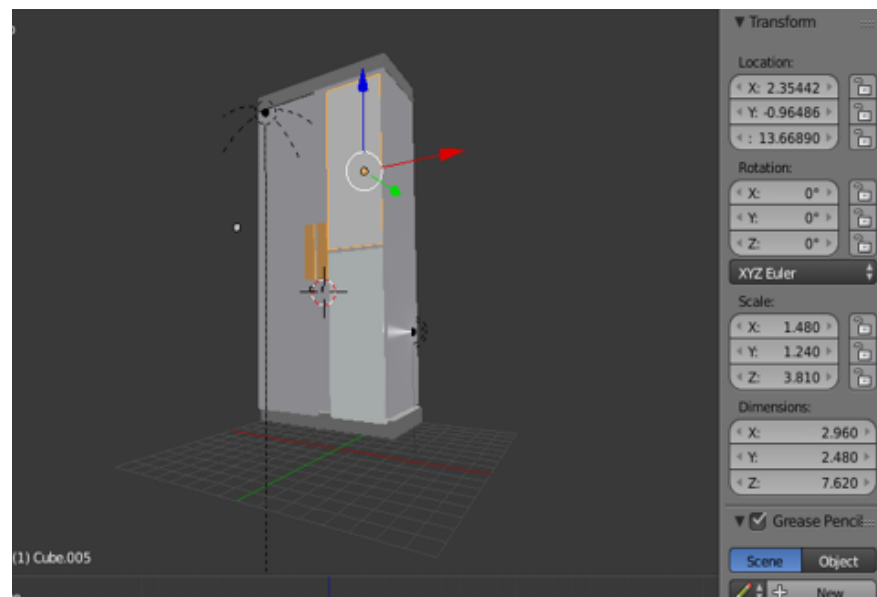


Figure 2. 3D modeling with blender.

3.2. Analysis

The functional requirements of the markerless Augmented Reality application were derived through a comprehensive needs analysis and direct observation of potential users during the planning phase. These requirements define the essential capabilities that the application must provide to ensure a meaningful and effective user experience. The implemented functional specifications, which form the core features of the application, are summarized in Table 1.

Table 1. Functional features of the AR application

No	Functional Requirement	Implemented Feature	Description
1	Display a list of available furniture products	Product Catalog Display	Users can browse a comprehensive list of furniture items available for visualization.
2	Select a product and display its detailed information	Product Detail View	Upon selection, users access detailed information about each furniture item, including descriptions and specifications.
3	Activate the AR camera and detect user-defined targets	AR Camera Activation & UDT Detection	The application activates the device's camera and initiates markerless tracking to identify a user-defined surface for virtual object placement.
4	Render a 3D virtual model of the selected furniture item	3D Model Rendering	The chosen furniture item is rendered as a 3D model within the real-world environment through the AR camera feed.
5	Enlarge (scale up) the 3D model	Object Scaling	Users can intuitively increase the size of the 3D furniture model to better visualize its spatial impact.
6	Reduce (scale down) the 3D model	Object Scaling	Users can decrease the size of the 3D model, allowing for flexible adjustments to fit various spaces.
7	Move or reposition the 3D model within the AR environment	Object Repositioning	Users can freely move and place the 3D model within their physical space, enabling accurate layout planning.

These core functionalities were designed to support interactive user engagement with virtual furniture models, allowing users to explore, position, and assess each item in a real-world spatial context. The ability to manipulate objects—by scaling and

repositioning—offers users flexibility to visualize furniture placement more accurately within their physical environment.

In addition to functional capabilities, the application was also specified with a set of non-functional requirements that describe the overall system attributes and operational conditions necessary to ensure performance, compatibility, and usability. The non-functional requirements include:

- **Platform Compatibility:** Based on Vuforia Library supported version, the application must be operable on Android devices running Android OS version 10.0 or higher, ensuring broad accessibility for users with a range of smartphones.
- **Camera Flexibility:** The AR system must be capable of recognizing and tracking user-defined targets from multiple viewing angles, enabling seamless interaction even when the device is tilted or moved dynamically.

These non-functional constraints ensure that the system performs reliably under typical user conditions and contributes to an intuitive and accessible user experience.

3.3. System Design

The architecture of the developed Augmented Reality (AR) system was designed to align with the functional and user experience requirements identified in the earlier stages of analysis. An overview of the system architecture is illustrated in Figure 3.

The application is designed as an AR-based furniture catalog that allows users to interactively visualize furniture items in real-world environments. The core concept is to integrate a virtual product catalog with AR functionality to enable users to not only browse furniture listings but also project and manipulate selected items within their actual space using a mobile device.

Each furniture item listed in the catalog is linked to a dedicated “AR Camera” feature. When a user selects a product from the catalog, the application transitions into AR mode, initializing a markerless tracking session using the device’s camera. The system prompts the user to identify a flat surface or specific object in the environment to serve as the User Defined Target (UDT). This surface or object becomes the anchor point where the selected 3D furniture model will appear.

This approach eliminates the need for physical markers and enhances user flexibility, as users can freely choose the placement location within their environment. The system supports dynamic tracking, allowing the virtual object to maintain alignment with the real-world context as the user moves their device or changes viewing angles.

By combining interactive product browsing, real-time AR visualization, and intuitive object placement, the system design addresses key usability goals: enabling users to assess the suitability of furniture within their space and make more confident purchasing decisions.

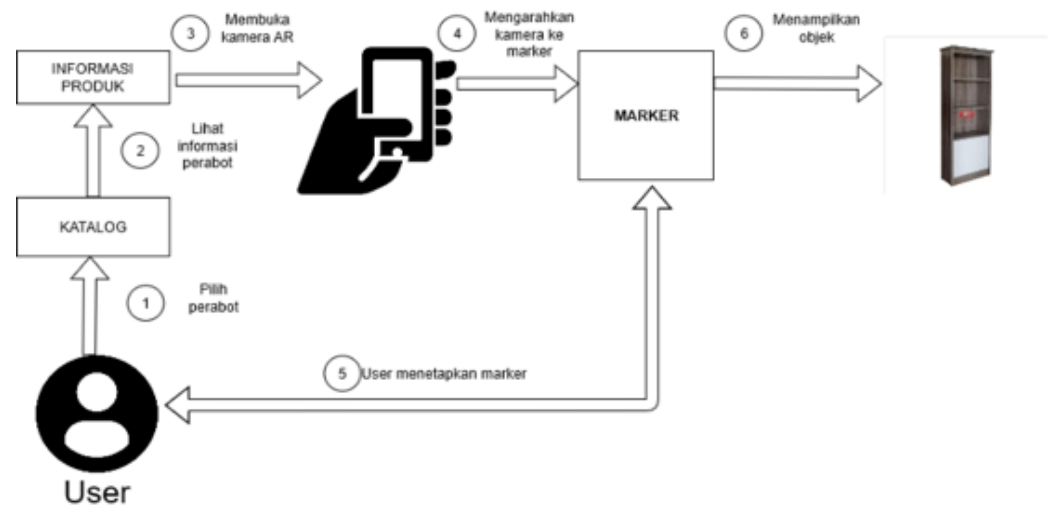


Figure 3. AR User-Defined Markerless system architecture.

3.4. Implementation

The implementation stage focused on integrating the system components and realizing the interactive Augmented Reality (AR) experience as outlined in the design phase. The 3D models of furniture products—comprising a sofa, bookshelf, wardrobe, and table—were constructed at a 1:10 scale, ensuring proportional consistency and rendering efficiency for use in mobile AR environments. These models were optimized for real-time visualization and interaction using Unity and Vuforia, ensuring compatibility with Android platforms.

In the application interface, the 3D furniture models were organized into a catalog-style layout (as shown in Figure 2) that allows users to browse and select products easily. Each item in the catalog is visually represented with high-fidelity previews, enabling users to make informed choices before engaging with the AR component.

Upon selecting a furniture item, the application activates the AR Camera and initiates a markerless tracking session. Users are prompted to designate a flat surface or real-world object—such as a floor, table, or wall—as a User Defined Target (UDT) to serve as the placement anchor. Once the target is detected, the corresponding 3D furniture object is rendered in real time at the specified location.

Figure 4 illustrates a successful placement scenario, in which a 3D table model is projected onto a real floor surface chosen by the user. The system maintains object stability and alignment as the user moves around the scene, allowing for continued inspection from multiple angles. This interaction simulates a realistic spatial context for evaluating the furniture’s appearance, fit, and compatibility with the existing environment.

The markerless implementation, powered by UDT, enhances user flexibility by removing the need for printed markers or fiducial codes, making the experience more intuitive and accessible. This phase demonstrates the system’s capability to bridge the gap between digital product catalogs and physical space through immersive visualization.

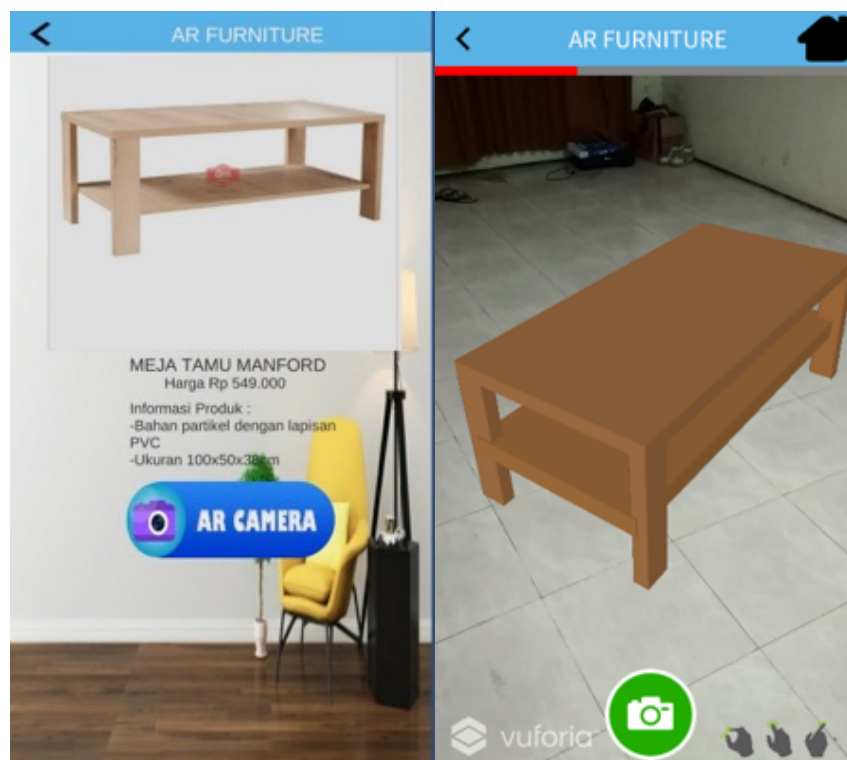


Figure 4. User-Defined Markerless interface.

4. Discussion

4.1. Angle-based testing

To evaluate the robustness and adaptability of the markerless AR system, angle-based testing was conducted using three different smartphones with varying camera specifications. The objective of this test was to determine the system's ability to accurately detect user-defined targets and render 3D furniture objects at various camera viewing angles. The testing procedure involved measuring performance across six predefined angles between the smartphone camera and the designated surface: 90°, 80°, 60°, 50°, 40°, and 30°. Vuforia Ground Plane Debug Visuals is used to measure the degree between camera and surface. The camera rotation my wrap around 0 - 360°, to get a normalized pitch angle between -90° to +90° we use `float pitch = arCamera.transform.eulerAngles.x; if (pitch > 180) pitch -= 360;` codes. Vuforia Ground Plane Debug live Visuals while detecting surface show in Figure 5.

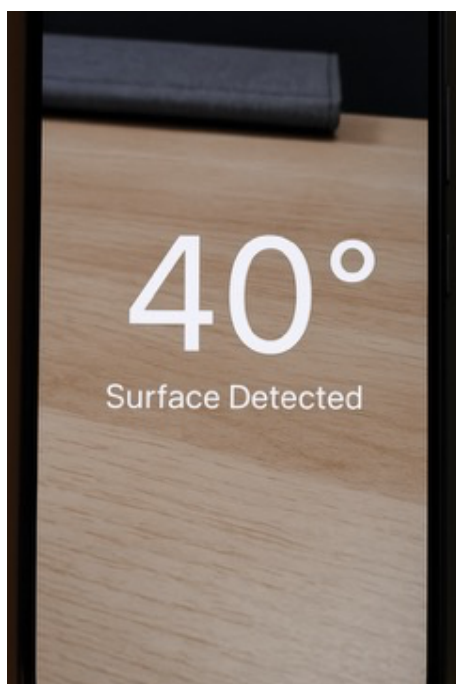


Figure 5. Live Vuforia Ground Plane Debug Visuals

The results of this evaluation are presented in Table 2, which summarizes the system's ability to display 3D objects under each angular condition for all three devices.

Table 2. Results of angle-based testing.

Device	Sudut						
	90	80	70	60	50	40	30
12 MP camera	√	√	√	√	√	√	-
13 MP camera	√	√	√	√	√	√	-
16 MP camera	√	√	√	√	√	√	-

As shown in Table 2, the system demonstrated consistent performance across most tested angles, from a direct overhead view (90°) down to a moderately tilted angle (40°). All three smartphones, regardless of their specific camera megapixel count, successfully rendered the 3D virtual furniture models within this range. This consistency suggests that the markerless tracking algorithm, supported by Vuforia's AR engine, effectively maintains environmental awareness and spatial coherence even under various viewing perspectives.

However, a notable and consistent limitation was observed at the 30° angle, where none of the devices were able to reliably display the 3D object. This indicates a critical threshold in the system's detection capability at more extreme angles, likely due to factors such as reduced surface visibility, insufficient environmental features for tracking, or a fundamental constraint of the underlying AR framework. These findings highlight the importance of maintaining an adequate viewing angle when interacting with AR content, particularly in markerless systems that rely heavily on robust surface recognition and spatial mapping. While the variation in camera specifications among the devices did not significantly impact performance at the more optimal angles, the uniform failure at 30° suggests a shared limitation across the tested hardware when operating under such challenging conditions.

4.2. Distance-based testing

In addition to angular performance, distance-based testing was conducted to assess the system's effectiveness in rendering 3D objects at varying distances between the smartphone camera and the user-defined target surface. The results of this evaluation are illustrated in Figure 6, which visualizes the system's rendering capabilities across different device configurations.

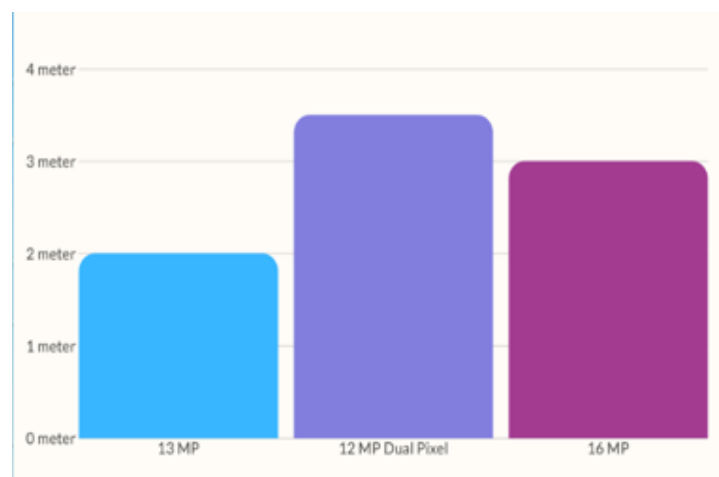


Figure 6. Result of distance-based testing.

The testing involved smartphones equipped with cameras of varying resolutions specifically, 12 MP and 16 MP. The results clearly indicated a significant difference in performance based on camera specifications. Devices with 12-megapixel cameras were able to display the 3D virtual objects reliably at a distance of up to 2 meters from the target surface. Beyond this range, object stability and recognition accuracy declined significantly, leading to tracking failure or improper object placement.

In contrast, smartphones equipped with higher-resolution 16-megapixel cameras demonstrated superior performance, successfully detecting user-defined targets and maintaining 3D object rendering at distances greater than 3 meters. This suggests that camera resolution plays a critical role in the accuracy and reliability of markerless AR systems, particularly when dealing with greater spatial separations between the device and the target surface. Higher resolution cameras can capture more detailed environmental features, which is crucial for the underlying algorithms to establish and maintain robust tracking at extended distances. These findings underscore the direct influence of hardware specifications—particularly camera resolution—on the usability and effective range of markerless AR applications.

For optimal user experience, the current system is best suited for usage within a 2–3 meter range, depending on device capabilities. This insight can guide system requirements for real-world deployment and inform recommendations for hardware compatibility in future development phases, emphasizing the benefit of higher-resolution cameras for more flexible use cases.

4.3. Usability testing

To assess the user experience and perceived usability of the developed AR-based furniture layout application, a usability evaluation was conducted using the System Usability Scale questionnaire. The SUS is a widely recognized and validated instrument for measuring the subjective usability of interactive systems, offering a standardized approach to quantifying user satisfaction, ease of use, and learnability.

The evaluation procedure involved a user trial, during which seven potential customers directly interacted with the application. These participants provided direct user feedback after performing a series of typical tasks within the app, such as selecting

furniture items, launching the AR view, positioning 3D models, and manipulating object properties.

Upon completing their session, respondents were required to fill out the SUS questionnaire, which consists of ten statements rated on a five-point Likert scale. These statements generally cover aspects of system usability such as perceived complexity, ease of use, need for technical support, integration of features, consistency, learning curve, and user confidence in using the system.



Figure 7. system usability scale interpretation guidelines.

The analysis of the SUS responses yielded a mean score of 72.1. According to standard SUS interpretation guidelines that shown in Figure 7, a score of 68 is considered the average, implying an "acceptable" level of usability. Therefore, the obtained score of 72.1 is above this global average, indicating that the application's usability is "Good" and falls within the range commonly associated with favorable user experiences. This result suggests that the application provides a user-friendly interface, with intuitive interactions and minimal cognitive load required to perform key functions.

The complete usability score breakdown for each respondent is presented in Table 3. While a score of 72.1 signifies good usability, this result indicates a robust and acceptable level of system usability. Further refinements could build upon this strong foundation to potentially achieve even higher user satisfaction.

Table 3. The usability evaluation results using SUS questionnaire.

Responden	Q1	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS score
1	4	2	2	3	3	3	3	4	4	60
2	4	3	1	3	1	4	3	5	4	72.5
3	3	3	4	3	4	3	3	2	3	42.5
4	3	1	1	3	1	4	1	5	1	87.5
5	3	1	1	3	1	5	1	4	2	85
6	4	2	2	3	2	4	3	5	2	72.5
7	3	2	1	3	1	5	1	5	2	85
Avg SUS Score										72.1

These results support the conclusion that the AR application meets general usability standards and is suitable for deployment among non-technical users, particularly potential customers exploring furniture options in real-world settings. The practical impact of

this "Good" usability score is significant: it suggests that the application can be easily adopted by its target audience without extensive training, fostering greater engagement and satisfaction. The positive usability outcome also reinforces the appropriateness of the Markerless User Defined Target approach, which likely contributed to the application's intuitive interaction model by removing the dependency on physical markers and enabling more natural user engagement with virtual content.

The present study significantly distinguishes itself from prior work through its explicit adoption and implementation of a Markerless User Defined Target methodology for augmented reality in furniture layout planning. Previous research and conventional AR applications have often relied on marker-based tracking methods, which require predefined physical markers to be present in the environment for virtual objects to be anchored. While effective, marker-based systems inherently introduce limitations such as restricted placement flexibility, the need for users to print or carry physical markers, and a less natural user experience.

Our approach, leveraging markerless UDT, overcomes these limitations by empowering users to freely select any suitable flat surface or object in their real-world environment as a target for virtual furniture placement. This innovative aspect directly enhances user experience by:

- **Eliminating physical markers:** Users are no longer burdened with the need for specific markers, making the application more accessible and convenient for on-the-go use.
- **Increasing flexibility and intuition:** The ability to choose any desired surface for placement allows for highly customized and natural visualization of furniture within actual living or commercial spaces. This intuitive interaction contrasts sharply with the rigid constraints of marker-based systems.
- **Enhancing real-world applicability:** By removing the dependency on markers, the application is suitable for a broader range of environments and user scenarios, from quick interior design previews to detailed spatial planning.

As highlighted by Brito and Stoyanova, markerless AR offers superior user experience and greater versatility compared to marker-based alternatives due to its inherent flexibility and reduced setup complexity [7]. Our findings corroborate this, demonstrating that the markerless UDT method significantly improves the fluidity of virtual object placement and interaction. This methodological innovation represents a crucial step forward in making AR furniture visualization truly seamless and user-centric, offering a superior method for consumers to confidently assess product suitability within their own environments. This directly addresses the psychological barriers in furniture purchasing identified in the Introduction, providing an adaptive and responsive visualization strategy that marker-based systems cannot fully achieve. The impact of this markerless innovation is a more accessible, flexible, and engaging AR experience, paving the way for wider adoption in retail and interior design applications.

5. Conclusions

This study successfully implemented the Markerless User Defined Target (UDT) method within an Augmented Reality (AR) application for furniture layout planning on the Android platform. The integration of the markerless UDT approach proved effective in delivering a more intuitive and flexible user experience compared to traditional marker-based systems, as it eliminates the dependency on physical markers and enhances user freedom in selecting real-world anchor points for object placement.

The usability evaluation, conducted using the System Usability Scale (SUS) questionnaire, resulted in an above-average score, categorizing the application as "acceptable." This indicates that the system demonstrates an adequate level of usability and is accessible

to users with varying levels of technical proficiency. Nevertheless, some respondents provided constructive feedback, highlighting opportunities for future enhancement—such as improving application responsiveness on low-specification devices.

The distance and angle testing further revealed that the application's performance is influenced by the camera specifications of the mobile devices used. Variations in sensor size and image quality across the three tested devices resulted in differing detection distances and effective viewing angles. The application was able to reliably detect AR objects within a viewing angle range of 90° to 40°, implying that hardware-specific optimization may be required to ensure a consistent user experience across a wider range of devices.

The primary contribution of this research lies in demonstrating the practical implementation of the markerless UDT approach in the context of mobile-based furniture layout planning. The developed application offers an innovative solution to visualization and interaction challenges in furniture marketing, enabling users to simulate the placement of virtual furniture in their own environment in real time, prior to making purchase decisions. This has a significant practical impact, as it directly addresses a key barrier in furniture purchasing the inability to visualize how an item will look and fit in a personal space thereby potentially increasing consumer confidence, reducing return rates for retailers, and streamlining the purchasing process. Additionally, this study provides important insights into the factors affecting the performance of markerless AR applications on mobile platforms particularly those related to camera hardware capabilities.

Looking to the long-term implications, this research lays foundational groundwork for the broader adoption of AR in the retail sector, particularly for large, tangible goods. The success of the markerless UDT method suggests a pathway toward more intuitive and widely accessible AR experiences, moving beyond niche applications. Future research should focus on enhancing application performance across various devices, improving tracking accuracy and scene understanding, and incorporating advanced features such as furniture appearance personalization, realistic lighting simulation, and seamless integration with e-commerce platforms to create a more comprehensive and commercially viable AR solution. This evolution could fundamentally alter how consumers interact with products before purchase, fostering more informed decisions and a more engaging shopping experience.

Acknowledgments: The authors would like to express their sincere gratitude to the staff of DM Mebel Yogyakarta for granting access to their showroom and allowing the use of their furniture products as reference materials for this study. Special thanks are also extended to the participants who volunteered their time to take part in the usability testing, providing valuable insights that contributed to the development and evaluation of the application. This research was conducted independently without external funding and was fully supported by the authors. Technical assistance, software tools, and computational resources were self-provided throughout the research and development process.

References

- [1] N. Chinthamu, A. Balaram, S. B. K, S. S, J. J S, and S. T, "Augmented Reality in Retail Transforming Shopping Experiences through Interactive Product Visualization," *ITM Web Conf.*, vol. 76, 2025, <https://doi.org/10.1051/itmconf/20257605010>
- [2] J. S. G. A. Balushi, M. I. A. A. Jabri, S. Palarimath, P. Maran, K. Thenmozhi, and C. Balakumar, "Incorporating Artificial Intelligence Powered Immersive Realities to Improve Learning using Virtual Reality (VR) and Augmented Reality (AR) Technology," in *2024 3rd International Conference on Applied Artificial Intelligence and Computing (ICAAIC)*, 2024, pp. 760–765. <https://doi.org/10.1109/ICAAIC60222.2024.10575046>.
- [3] W. Bin Latif, I. Yasin, M. A. Rahaman, M. Forid, M. Islam, and M. Hossain, "Impact of Augmented Reality (AR) and Virtual Reality (VR) on Interactive Learning Systems," *Pacific Journal of Advanced Engineering Innovations*, vol. 1, no. 1, Dec. 2024, <https://doi.org/10.70818/pjaei.2024.v01i01.016>.

- [4] A. Pellegrino, "Consumer Expectations in the Digital Environment," in *Decoding Digital Consumer Behavior: Bridging Theory and Practice*, A. Pellegrino, Ed., Singapore: Springer Nature Singapore, 2024, pp. 61–76. https://doi.org/10.1007/978-981-97-3454-2_5.
- [5] N. Anifa and S. Sanaji, "Augmented Reality Users: The Effect of Perceived Ease of Use, Perceived Usefulness, and Customer Experience on Repurchase Intention," *Journal of Business and Management Review*, vol. 3, no. 3, pp. 252–274, Mar. 2022, <https://doi.org/10.47153/jbmr33.3462022>.
- [6] J. Yu, S. (Sam) Kim, T. B. Hailu, J. Park, and H. Han, "The effects of virtual reality (VR) and augmented reality (AR) on senior tourists' experiential quality, perceived advantages, perceived enjoyment, and reuse intention," *Current Issues in Tourism*, vol. 27, no. 3, pp. 464–478, Feb. 2024, <https://doi.org/10.1080/13683500.2023.2165483>.
- [7] P. Q. Brito and J. Stoyanova, "Marker versus Markerless Augmented Reality. Which Has More Impact on Users?," *Int J Hum Comput Interact*, vol. 34, no. 9, pp. 819–833, Sep. 2018, <https://doi.org/10.1080/10447318.2017.1393974>.
- [8] M. Eswaran and M. V. A. R. Bahubalendruni, "Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: A state of the art review," *J Manuf Syst*, vol. 65, pp. 260–278, 2022, <https://doi.org/10.1016/j.jmsy.2022.09.016>.
- [9] S. Yoo, S. Reza, H. Tarashiyoun, A. Ajikumar, and M. Moghaddam, "AI-Integrated AR as an Intelligent Companion for Industrial Workers: A Systematic Review," *IEEE Access*, vol. 12, pp. 191808–191827, 2024, <https://doi.org/10.1109/ACCESS.2024.3516536>.
- [10] Y. Huang, O. Taheri, M. J. Black, and D. Tzionas, "InterCap: Joint Markerless 3D Tracking of Humans and Objects in Interaction from Multi-view RGB-D Images," *Int J Comput Vis*, vol. 132, no. 7, pp. 2551–2566, Jul. 2024, <https://doi.org/10.1007/s11263-024-01984-1>.
- [11] R. Kataria, P. Pathak, A. Fatma, V. Bhatt, and P. Kumar, "The Role of Augmented Reality (AR) in Retail Marketing: Enhancing Customer Engagement and In-store Experiences," in *2024 International Seminar on Application for Technology of Information and Communication (iSemantic)*, 2024, pp. 223–228. <https://doi.org/10.1109/iSemantic63362.2024.10762095>.
- [12] J.-Y. Zeng, Y. Xing, and C.-H. Jin, "The Impact of VR/AR-Based Consumers' Brand Experience on Consumer–Brand Relationships," *Sustainability*, vol. 15, no. 9, p. 7278, Apr. 2023, <https://doi.org/10.3390/su15097278>.
- [13] B. Berman and D. Pollack, "Strategies for the successful implementation of augmented reality," *Bus Horiz*, vol. 64, no. 5, pp. 621–630, 2021, <https://doi.org/10.1016/j.bushor.2021.02.027>.
- [14] A. Garg, A. Kumar, Y. Rani, and G. Kaur, "Augmented Reality in E-Commerce: Unveiling the Future of Online Shopping," in *2024 Sixth International Conference on Computational Intelligence and Communication Technologies (CCICT)*, IEEE, Apr. 2024, pp. 356–363. <https://doi.org/10.1109/CCICT62777.2024.00065>.
- [15] S. Li, H.-Y. Kim, and S.-J. Yoon, "AR(Augmented Reality) Experiences and Tourist Engagement: Verifying the Role of Destination Brand Relationship, Immersion, and Emotional Attachment," *GLOBAL BUSINESS FINANCE REVIEW*, vol. 29, no. 11, pp. 1–15, Dec. 2024, <https://doi.org/10.17549/gbfr.2024.29.11.1>.
- [16] P. Soon, W. M. Lim, and S. S. Gaur, "The role of emotions in augmented reality," *Psychol Mark*, vol. 40, no. 11, pp. 2387–2412, Nov. 2023, <https://doi.org/10.1002/mar.21884>.
- [17] Joy Onma Enyejo, Omotoyosi Qazeem Obani, Olusegun Afolabi, Emmanuel Igba, and Akan Ime Ibokette, "Effect of Augmented Reality (AR) and Virtual Reality (VR) experiences on customer engagement and purchase behavior in retail stores," *Magna Scientia Advanced Research and Reviews*, vol. 11, no. 2, pp. 132–150, Jul. 2024, <https://doi.org/10.30574/msarr.2024.11.2.0116>.