Innovations in Interior Room Design using Markerless Augmented Reality Mobile-based Simultaneous Localization and Mapping Algorithm

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ABSTRACT

Interior design is a process of designing, planning, and creating an environment within a space to meet the needs of its occupants. Interior design also plays a crucial role in creating a space that fulfills users' physical and spiritual needs while maintaining aesthetic aspects. However, to visualize interior designs in real-time, homeowners often face limitations in physically moving furniture into the room to see the exact positions. Therefore, a system is needed to assist in decision-making during interior design. This paper discussed the integration of markerless augmented reality methods with the Simultaneous Localization and Mapping (SLAM) algorithm to map the surrounding environment as a basis for determining the position of virtual objects. The system developed in this research enabled users to view virtual objects such as furniture in real-time within the existing space without physically moving or shifting furniture. Users could select the desired furniture, and the system accurately displayed the objects in the appropriate scale and position based on the environment mapping performed using SLAM. As a result, homeowners could visualize their desired interior designs before making significant physical changes. The outcome of this research was a system that could be utilized for virtual interior design, decision-making processes, and improved visualization of interior designs.

General Terms

Android, Unity, C#

Keywords

Simultaneous localization and mapping, Markerless augmented reality, Visualization, Interior design, Mobile application.

1. INTRODUCTION

Augmented reality (AR) has opened up new opportunities in various fields, including interior room design. AR can create interactions between the real world and the virtual world, where all information can be added and displayed in real-time, making it appear interactive and realistic [1]. In this context, interior room design utilizing augmented reality technology has become an interesting area of research to be explored.

Interior design is a series of processes that involve planning a space facility to meet its users' physical and psychological needs. Interior design involves not only planning the facilities within a space but also creating an ambiance that positively impacts its users [2]. In the interior design industry, the use of augmented reality (AR) technology is increasingly advancing to assist designers in visualizing design concepts more realistically. With the continuous advancement of technology, AR has become an effective solution for addressing issues in interior design visualization [3].

Augmented Reality (AR) is a technology that combines computer-generated images with the user's perspective of the real world, creating a composite view [4]. There are two methods commonly used in augmented reality (AR) development: marker-based tracking and markerless tracking [5]. Marker-based tracking involves tracking based on markers or patterns placed on a medium [6]. On the other hand, markerless tracking does not require markers and instead utilizes pattern recognition from actual objects [7]. In that context, the author used the markerless method to provide a visual representation of the 3D object model for interior room design.

The utilization of augmented reality technology in the design of interior spaces represents an innovative and interactive approach. Augmented reality, through its advanced features including object selection, precise measurements, and immersive 3D product visualization, offers users a remarkably realistic visual experience, enabling them to gain a clear and vivid preview of how the proposed interior design will seamlessly integrate into the actual physical environment.

This research proposes the design of an augmented reality application for interior room design that utilizes tools capable of detecting environmental conditions. One of the tools that can detect environmental conditions is Simultaneous Localization and Mapping (SLAM) [8]. Simultaneous Localization and Mapping (SLAM) is a technique in which a device or system can accurately create a real-time map of its physical environment, determining the device's position and orientation within that map [9].

This research aimed to apply augmented reality technology using the markerless augmented reality method with the Simultaneous Localization and Mapping (SLAM) algorithm in interior room design. The study aimed to develop a system that allowed users to interactively design and view real-time visualizations of interior room designs using augmented reality devices. The markerless augmented reality method enabled users to intuitively visualize and explore desired interior designs without requiring specific markers [10]. With the assistance of the SLAM algorithm, the system accurately tracked the device's position and orientation within the room, enabling users to place objects and design elements precisely. The main goal was to provide a more realistic and intuitive experience for users in planning and visualizing interior designs, as well as to improve efficiency and quality in the overall room design process.

2. RESEARCH METHOD

The research methodology used in this study comprised four main stages that involved software and hardware analysis, system architecture design, 3D object implementation, and

application implementation. In this section, each stage was explained in detail to provide a comprehensive overview of the process of creating an augmented reality application for interior room design.

2.1 Software and Hardware Analysis

The software and hardware analysis was an important step in determining the system requirements and specifications for developing the augmented reality (AR) application. These specifications outlined the necessary elements or components needed to build the system before implementation could take place. Additionally, the requirements analysis determined the input specifications needed for the system [11]. The software and hardware analysis for creating the augmented reality (AR) interior design application are as follows:

2.1.1. Software Requirements

Software analysis was an important aspect to support system performance [12]. The software used by the system consisted of instructions given to the hardware to interact with each other. The following software was used to create this augmented reality application:

Table 1 Software Requirements

No.	Software	Specifications
Laptop		
1.	Operating System	Windows 11 64-bit
2.	Development Tool	Unity 2021.3.9f1
3.	Design Tool	Figma
4.	Asset Design Tool	Blender
Mobile		
1.	Operating System	Android
2.	Version	Android 11

2.1.2. Hardware Requirements

Hardware analysis was important because, without hardware that met the requirements, the built program would not have been able to run [13]. The hardware specifications used to create this application were as follows:

Table 2 Hardware Requirements

No.	Hardware	Specifications
Laptop		
1.	Processor	11th Gen Intel(R) Core(TM) i5-11400H @ 2.70GHz 2.69 GHz
2.	Memory	16 GB
3.	Storage	512 GB SSD
4.	Monitor	15"(inch)
Mobile		
1.	Screen	6.6"(inch)
2.	RAM	8 GB
3.	SD Card	128 GB
4.	Camera	50 MP

2.2 System Architecture

System architecture analysis was an important process in software development that aimed to identify and analyze the key elements of the system. By conducting a proper architecture analysis, it facilitated software development and minimized the risk of system failure. System architecture analysis was crucial to ensure an optimal and efficient system for users. In this case, the system architecture that was created was augmented reality as a tool for interior room layout design. The illustration of System Architecture is shown in Fig 1.
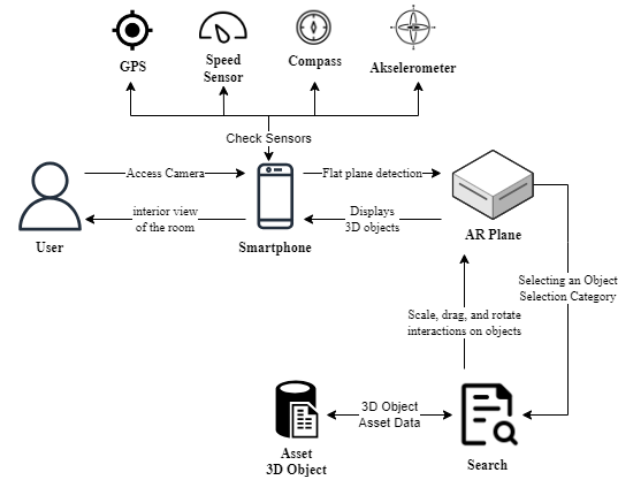

Fig 1 System Architecture

In the application architecture, there were several components involved. First, there was the user, who used the augmented reality application. The user utilized the camera on their smartphone to access AR scanning. Then, the smartphone checked the sensors on the device to access markerless augmented reality technology. Next, the smartphone detected flat surfaces in the room. Once a flat surface was successfully detected, the user could choose from different object categories in the interior design augmented reality application. There were three options: living room, bedroom, and bathroom. After selecting an object, the corresponding 3D asset data was called and displayed on the previously detected flat surface. At this stage, the user could interact with the 3D asset by scaling, dragging, and rotating it according to their preferences. Subsequently, the 3D object was shown on the smartphone, allowing the user to capture images of the designed interior space.

2.3 Implementasi 3D Object

The implementation of 3D objects was an important aspect in creating the augmented reality application, where the models (3D objects) were displayed based on the detected flat surfaces by the system. The tool used for creating 3D objects was Blender, which was a free and open-source 3D design software [14]. Blender supported the entire 3D workflow, including modeling, rigging, animation, simulation, rendering, compositing, motion tracking, video editing, and game creation [15].

In creating 3D object models of interior furniture with Blender, several steps could be followed. First, the design and references were analyzed to gain a clear understanding of the furniture that was to be created. Next, the modeling tools in Blender were used to create the basic shapes of the furniture, such as tables, chairs, or cabinets, while paying attention to accurate proportions and details. After that, suitable textures and materials were applied to give a realistic appearance to the

furniture. Subsequently, the lighting and placement of the furniture within the room were adjusted to see how the furniture interacted with the surrounding environment. Lastly, the rendering process was carried out to produce images or animations of the 3D interior furniture that could be used for room visualization. The process of Implementation 3D virtual objects is shown in Fig 2.
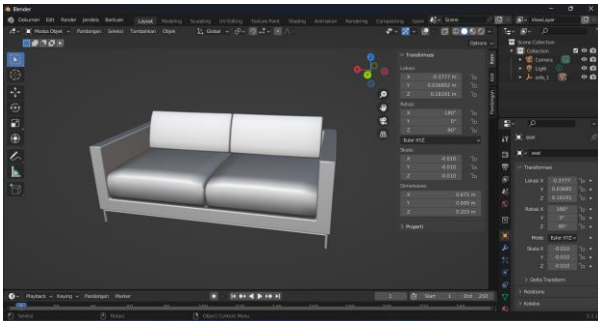

Fig 2 Implementation 3D Virtual Objects

2.4 Application Implementation

The application implementation provided an explanation for developing an augmented reality interior design application. The interior design application was built using the C# language and Unity 3D, with Visual Studio Code added as the text editor. Unity was an application to create and develop multi-platform games, including Windows, Mac, and mobile platforms. Unity itself was a software frequently utilized by professionals. Unity offered drag-and-drop capabilities in its visual workflow, and supported programming in the widely renowned C# language. Unity supported the development of 3D and 2D graphics, providing a set of tools for both types of graphics that continued to evolve, making them increasingly user-friendly with each update [16].

Several steps could have been followed in developing an interior design application with Unity. Firstly, the visual assets, such as 3D models, textures, and design materials, were gathered and prepared. Next, a new project was created in Unity, and these assets were imported into the project. Then, scripts were created to provide commands to the application, such as menu navigation, capturing images, and others. After that, a tracking and object placement system was developed in the real world using AR technologies like ARKit or ARCore. Next, interaction mechanisms were implemented, allowing users to select objects or modify room layouts.

The following was a scan handler script that functioned to manage the transitions or navigation to various menus within the interior layout design application. In this application, the scan handler played a vital role in managing user navigation and ensuring a smooth and intuitive user experience. The script of scan handler is shown in Fig 3.

Fig 3 Script Scan Handler

In addition to the scan handler script, there was also a ButtonSFX script that could be used to add sound effects to each button in the application's menu. By using this script, whenever a user pressed a button, a corresponding sound would be played to enhance the user experience while interacting with the application. The script of ButtonSFX is shown in Fig 4.

Fig 4 Script ButtonSFX

There was also an AudioManager script that could be used to add background music (backsound) to the application being used. This script helped in managing the automatic playback of music and provided better control over the music that was being played. The script of AudioManager is shown in Fig 5.

```
D: > LATIHAN > AR Furniture AR Foundation Markerless > Assets > C# AudioManager.cs
 1    using System.Collections;
 2    using System.Collections.Generic;
 3    using UnityEngine;
 4
 5    public class AudioManager : MonoBehaviour
 6    {
 7        public static AudioManager instance;
 8        public AudioSource btnSfxSource;
 9        private void Awake()
10        {
11            if(instance == null)
12            {
13                instance = this;
14                DontDestroyOnLoad(gameObject);
15            }
16            else
17            {
18                Destroy(gameObject);
19            }
20        }
21        public void PlayButtonSfx()
22        {
23            btnSfxSource.Play();
24        }
25    }
26
```

Fig 5 Script AudioManager

To run the scan handler script, the configuration was needed in the application settings within Unity. At that stage, the scan handler script was added to the interior design application project in Unity, which managed the transitions or navigation to various menus within the interior layout design application. The process of Configuration Scene Handler is shown in Fig 6.
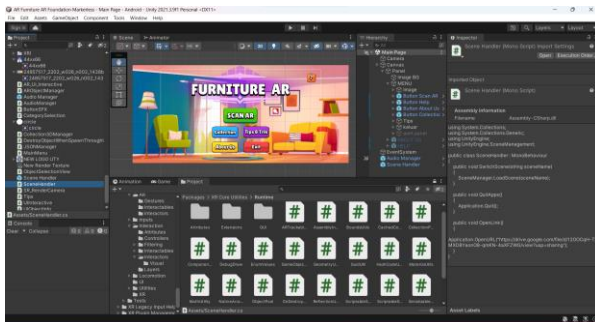

Fig 6 Configuration the Scene Handler in Unity

Running the function of ButtonSFX, which added sound effects to each menu in the application created in Visual Studio Code. The process of Configuration ButtonSFX is shown in Fig.7.

Fig 7 Configuration the ButtonSFX in Unity

After successfully running the function of ButtonSFX, the function of the audio manager was executed to add background music to the application created in Visual Studio Code. The process of Configuration audio manager is shown in Fig 8.
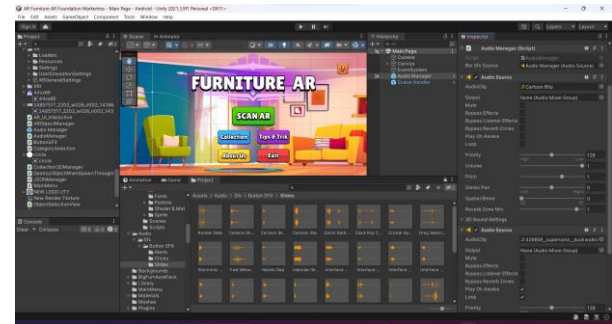

Fig 8 Configuration the Audio Manager in Unity

3. RESULT

The application design outcome provided an explanation that covered the implementation of the built augmented reality (AR) program [17], it included the interface of the home page and the implementation of the appearing 3D objects. Furthermore, in the application design outcome, technical testing was conducted on several smartphone devices to determine whether the application could be installed and operated smoothly on different devices.

3.1 Program Implementation

3.1.1 Home Page Interface

The background of the home page interface utilized an animated image of an interior design to depict the application's focus on interior design. There were six main menus on the home page: AR Scan, Collection, Tips & Tricks, About Us, Help, and Exit. The interface of the main menu is shown in Fig 9.

Fig 9 Home Page Interface

3.1.2 AR Scan Page Interface

The dedicated AR scan page was meticulously crafted to seamlessly execute markerless augmented reality experiences, enhancing the user's interaction with the application. It ingeniously amalgamated cutting-edge Simultaneous Localization and Mapping (SLAM) algorithms, thereby empowering the application to precisely track the device's position and orientation within any given room. This innovative AR Scan feature streamlined the process for users, allowing them to effortlessly harness its capabilities by simply directing their device's camera towards any flat surface or AR plane, effectively serving as an intuitive canvas for placing the diverse range of furniture objects available within the application's expansive library.

The image below offers a tangible glimpse into one of the implementations of the 3D furniture mode, an integral feature within the realm of this interior design augmented reality application. Here, users were granted the creative liberty to arrange the displayed 3D models in accordance with their individual preferences, fostering a bespoke and tailored design

experience. For a more detailed overview of the AR scan's interface, please consult Fig 10.

Fig 10 AR Scan Page Interface

3.1.3 Collection Page Interface

The collection page, a fundamental component of the application's architecture, functioned as a comprehensive repository for various asset collections and an extensive array of 3D models. Within this multifaceted page, three distinct options were presented to users, namely the living room, bedroom, and bathroom categories, each housing an assortment of meticulously curated objects. Users had the convenience of accessing detailed descriptions and specifications pertaining to their selected objects directly from this interface. For a visual representation of the collection page's layout and features, please refer to Fig 11.

Fig 11 Collection Page Interface

3.1.4 Tips & Tricks Page Interface

The tips & tricks page contained valuable tips and tricks related to interior design. This page also featured a back button that allowed users to return to the main menu. The interface of the tips & tricks is shown in Fig 12.
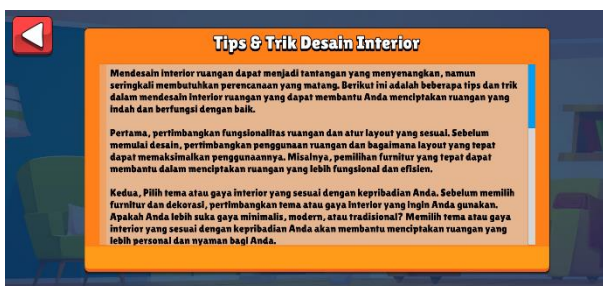

Fig 12 Tips & Tricks Page Interface

3.1.5 About Us Page Interface

The About Us page provided information about the developers of the interior design augmented reality application. This page also featured a back button that allowed users to return to the main menu. The interface of the about us is shown in Fig 13.

Fig 13 About Us Page Interface

3.1.6 Help Page Interface

The Help page contained information on how to use the interior design augmented reality application. This page also featured a back button that allowed users to return to the main menu. The interface of the help is shown in Fig 14.
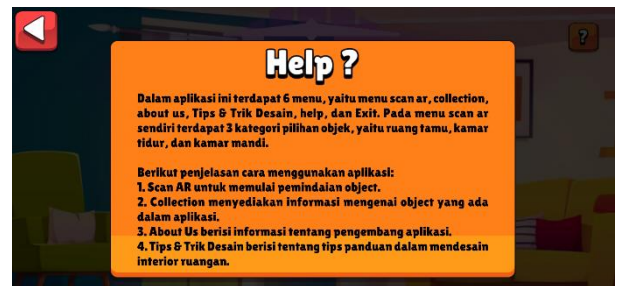

Fig 14 Help Page Interface

3.1.7 Exit Alert Pop-up Interface

The Exit Alert pop-up would appear when the user clicked the exit button. The pop-up displayed informative text that guided the user to make a decision whether to leave the application or stay within it. The interface of the exit alert pop-up is shown in Fig 15.

Fig 15 Exit Alert Pop-up Interface

3.2 Application Testing

The application was tested in two ways: performance testing and compatibility testing. Performance testing aimed to assess the performance of the developed application, while compatibility testing aimed to ensure that the interior design augmented reality application could run smoothly on different Android devices with varying specifications.

3.2.1 Application Performance Testing

Performance testing was conducted to evaluate the performance of the developed application. The aspects tested included resource consumption, application performance, and processing time. The specifications of the devices used in the testing are listed in the table 3.

Table 3 Testing Device Specifications

No.	Hardware	Specification
1.	Chipset	Qualcomm SM6225 Snapdragon 680 4G
2.	RAM	8 GB
3.	SD Card	128 GB
4.	Battery	5.000 mAh

Overall, the performance of the interior design application based on augmented reality has been tested, and the results are shown in the table 4.

Table 4 Application Performance Testing

No.	Performance	Result
1.	File size (*.apk)	49,2 MB
2.	Application size after installation	105 MB
3.	Total memory usage while running	116 MB
4.	Power consumption during app usage	26,25%
5.	Time take to open the application	1 second
6.	Time take open a menu	0,5 second

The comprehensive evaluation of the tested augmented reality (AR) application designed for interior room design unveiled a spectrum of positive outcomes. Remarkably, the installation file size, initially measured at a moderate 49.2 megabytes, expanded to 105 megabytes after installation. This increase in size post-installation was a direct consequence of the indispensable resources necessary to support the intricate functionalities inherent in markerless augmented reality (AR) experiences.

Throughout the application's runtime, its memory usage remained notably conservative, peaking at a mere 26.25% of the total available memory on the device. This observation underscores the application's efficiency, affirming that it placed minimal strain on the device's memory resources. Consequently, users were afforded a seamless and responsive experience, reinforcing the application's ability to deliver uninterrupted performance.

Furthermore, the application's speed exhibited remarkable swiftness, with the time required to launch the application measured at a mere one-second interval. Similarly, the swift response time of approximately 0.5 seconds for menu navigation further solidified the application's user-friendly design. These expedited response times not only underscored the application's technical prowess but also contributed significantly to a fluid and gratifying user experience, characterized by instantaneous interactions.

In summation, considering the judicious file size, efficient memory utilization, and lightning-fast response times, it is evident that this augmented reality (AR) application demonstrated commendable performance capabilities. Its

capacity to seamlessly facilitate the design of interior spaces through augmented reality (AR) technology underscores its potential in delivering a gratifying and immersive user experience.

3.2.2 Compatibility Testing

The purpose of compatibility testing was to determine if the augmented reality-based interior design application could run smoothly on different Android devices with varying specifications. The results of the application's compatibility testing on various Android devices can be seen in the table 5.

Table 5 Compatibility Testing

No.	Device	Processor	RAM	Camera	Result
1.	Redmi Note 8	Snapdragon 665	4GB	48MP	Smooth
2.	Redmi Note 10	Snapdragon 678	4GB	48MP	Smooth
3.	Poco X2	Snapdragon 730	6GB	64MP	Smooth
4.	Samsung J5 PRO	Octa-Core Cortex-A53	3GB	13MP	Smooth
5.	Oppo f15	MediaTek Helio P70	4GB	48MP	Smooth

This application has been tested on different devices, and the testing results have shown good compatibility. The application runs smoothly on the Redmi Note 8 device with a Snapdragon 665 processor, 4 GB RAM, Android version 9.0, and a 48 MP camera. Users can easily access the application's features and utilize augmented reality (AR) technology to design interior spaces. The same applies to the Redmi Note 10 device with a Snapdragon 678 processor, 4 GB RAM, Android version 11, and 48 MP camera, where the application runs smoothly and provides a satisfying experience for users.

Furthermore, the Poco X2 device with Snapdragon 730 processor, 6 GB RAM, Android version 10, and 64 MP camera has also proven to be compatible with this application. Users of this device can effortlessly run the augmented reality (AR) interior design application without significant obstacles or lag. With higher specifications, Poco X2 users can enjoy richer visualizations and a more interactive experience when designing interior spaces through this application.

This application also demonstrated good compatibility with other devices, such as the Samsung Galaxy J5 Pro with Octa-Core Cortex-A53 processor, 3 GB RAM, Android version 7.0, and a 13 MP camera. Despite having lower specifications compared to other devices, the Samsung Galaxy J5 Pro was still able to run the application smoothly and provide a satisfying experience to users. Additionally, the Oppo F15 with MediaTek Helio P70 processor, 4 GB RAM, Android version 9.0, and 48 MP camera was also proven to be compatible with this application, offering Oppo F15 users access to the interior design AR features without significant obstacles.

Based on the testing on various devices, this application demonstrated compatibility with various devices, including the Redmi Note 8, Redmi Note 10, Poco X2, Samsung Galaxy J5 Pro, and Oppo F15. The good compatibility on devices with

diverse specifications showcased the application's flexibility in running smoothly across various platforms. Users of these devices could utilize the application to design interior spaces with a seamless and satisfying experience.

4. DISCUSSION

The results of this research indicated that using the markerless augmented reality (AR) method with the Simultaneous Localization and Mapping (SLAM) algorithm significantly contributed to interior design. The markerless augmented reality (AR) method allowed users to place virtual objects directly in physical spaces without needing specific markers. As a result, users could intuitively visualize and explore their desired interior designs using their mobile devices. The Simultaneous Localization and Mapping (SLAM) algorithm used in the application helped recognize and track the device's position and orientation within the room, enabling accurate placement of virtual objects and providing a realistic experience for users.

Additionally, using the markerless augmented reality (AR) method also offers advantages in terms of flexibility and convenience. In this testing, there was no need to place physical markers around the room, allowing users to easily access and use the application in various environments and situations. Users could directly initiate the interior design process simply by using the camera of their mobile devices. This provided greater flexibility in the application's usage and allowed users to design interior spaces anytime and anywhere according to their needs.

In this testing, achieving a satisfying user experience was a significant outcome. Users were able to easily visualize interior design objects within their physical spaces with a high level of accuracy. The virtual objects displayed by the AR application had good detail and smooth rendering, creating a realistic appearance and providing a clear depiction of the desired interior design outcome. The application's responsiveness in responding to changes in the user's position and orientation was also proven to be excellent, allowing users to interact with virtual objects easily and intuitively.

5. CONCLUSSION

This paper concluded that the use of the markerless augmented reality (AR) method with the Simultaneous Localization and Mapping (SLAM) algorithm significantly contributed to the interior design of interior spaces with a satisfying user experience. The markerless augmented reality (AR) method allowed users to intuitively visualize and explore their desired interior designs without needing specific markers. The Simultaneous Localization and Mapping (SLAM) algorithm helped recognize and track the device's position and orientation within the space, enabling high-precision placement of virtual objects and providing a realistic experience. This method also offered flexibility and convenience in application usage, without the need for physical markers, and could be used in various environments. The testing also demonstrated a satisfying user experience, where users could easily visualize interior design objects with a good level of accuracy and high application responsiveness.

While significant progress has been made in the testing and implementation of this method, there is significant potential for further development in the future. The development of more complex and realistic augmented reality (AR) models may be the next focus of research. With the increasing computational power and stronger hardware, we can anticipate more visual detail in virtual objects placed within interior spaces. This will create a deeper experience for users and assist in making better design decisions. Thus, the use of markerless augmented reality (AR) with Simultaneous Localization and Mapping (SLAM) is a significant breakthrough in the interior design industry. Through ongoing research and development, we can expect to witness even greater transformations in how we interact with everyday spaces.

6. REFERENCES

[1] D. Kristina and U. P. Raya, "Artikel aplikasi augmented reality karakter olaf," no. December, 2022.

[2] A. A. Rucitra, "Merumuskan Konsep Desain Interior," *J. Desain Inter.*, vol. 5, no. 1, p. 31, 2020, doi: 10.12962/j12345678.v5i1.7020.

[3] E. Tryana and L. Rusdiana, "Augmented Reality-Based Application Design for the Introduction of Rattan Furniture," *J. Appl. Sci. Technol.*, vol. 2, no. 01, p. 1, 2022, doi: 10.30659/jast.2.01.1-6.

[4] P. Subhashini, R. Siddiqua, A. Keerthana, and P. Pavani, "Augmented Reality in Education," *J. Inf. Technol. Digit. World*, vol. 02, no. 04, pp. 221–227, 2020, doi: 10.36548/jitdw.2020.4.006.

[5] J. Dwi Gotama, Y. Fernando, and D. Pasha, "Pengenalan Gedung Universitas Teknokrat Indonesia Berbasis Augmented Reality," *J. Inform. dan Rekayasa Perangkat Lunak*, vol. 2, no. 1, pp. 28–38, 2021, [Online]. Available: http://jim.teknokrat.ac.id/index.php/informatika

[6] R. Romli, A. F. Razali, N. H. Ghazali, N. A. Hanin, and S. Z. Ibrahim, "Mobile Augmented Reality (AR) Marker-based for Indoor Library Navigation," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 767, no. 1, 2020, doi: 10.1088/1757-899X/767/1/012062.

[7] E. Barcali, E. Iadanza, L. Manetti, P. Francia, C. Nardi, and L. Bocchi, "Augmented Reality in Surgery: A Scoping Review," *Appl. Sci.*, vol. 12, no. 14, pp. 1–16, 2022, doi: 10.3390/app12146890.

[8] Z. Hong, Y. Petillot, and S. Wang, "RadarSLAM: Radar based large-scale SLAM in all weathers," *IEEE Int. Conf. Intell. Robot. Syst.*, pp. 5164–5170, 2020, doi: 10.1109/IROS45743.2020.9341287.

[9] A. Dhakal, X. Ran, Y. Wang, J. Chen, and K. K. Ramakrishnan, "SLAM-Share: Visual Simultaneous Localization and Mapping for Real-time Multi-user Augmented Reality," *Conex. 2022 - Proc. 18th Int. Conf. Emerg. Netw. Exp. Technol.*, pp. 293–306, 2022, doi: 10.1145/3555050.3569142.

[10] N. El Barhoumi, R. Hajji, Z. Bouali, Y. Ben Brahim, and A. Kharroubi, "Assessment of 3D Models Placement Methods in Augmented Reality," *Appl. Sci.*, vol. 12, no. 20, 2022, doi: 10.3390/app122010620.

[11] R. Li, W. J. C. Verhagen, and R. Curran, "A systematic methodology for Prognostic and Health Management system architecture definition," *Reliab. Eng. Syst. Saf.*, vol. 193, no. August 2019, p. 106598, 2020, doi: 10.1016/j.ress.2019.106598.

[12] J. L. Kwan *et al.*, "Computerised clinical decision support systems and absolute improvements in care: Meta-analysis of controlled clinical trials," *BMJ*, vol. 370, 2020, doi: 10.1136/bmj.m3216.

[13] G. M. Santi, A. Ceruti, A. Liverani, and F. Osti,

"Augmented Reality in Industry 4.0 and Future Innovation Programs," *Technologies*, vol. 9, no. 2, 2021, doi: 10.3390/technologies9020033.

[14] B. Mrugalska *et al.*, "Open source systems and 3D computer design applicable in the dental medical engineering Industry 4.0 – sustainable concept," *Procedia Manuf.*, vol. 54, pp. 296–301, 2021, doi: 10.1016/j.promfg.2021.09.002.

[15] I. A. Astuti, I. H. Purwanto, T. Hidayat, D. A. Satria, Haryoko, and R. Purnama, "Comparison of Time, Size and Quality of 3D Object Rendering Using Render Engine Eevee and Cycles in Blender," *2022 5th Int. Conf. Comput. Informatics Eng. IC2IE 2022*, pp. 54–59, 2022, doi: 10.1109/IC2IE56416.2022.9970186.

[16] A. Hussain, H. Shakeel, F. Hussain, N. Uddin, and T. L. Ghouri, "Unity Game Development Engine: A Technical Survey," *Univ. Sindh J. Inf. Commun. Technol.* , vol. 4, no. 2, pp. 73–81, 2020, [Online]. Available: http://sujo.usindh.edu.pk/index.php/USJICT/

[17] N. Dengen, H. S. Pakpahan, G. F. Putra, M. B. Firdaus, R. Wardhana, and A. Tejawati, "An Augmented Reality Model Physical Transformation Learning," *ICEEIE 2019 - Int. Conf. Electr. Electron. Inf. Eng. Emerg. Innov. Technol. Sustain. Futur.*, pp. 255–259, 2019, doi: 10.1109/ICEEIE47180.2019.8981444.