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Augmented Reality Interior Design Application

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ABSTRACT

Augmented Reality (AR) has revolutionized the interior design industry by offering fresh solutions for real-time visualization, personalization, and enhanced user experience. By presenting or overlaying digital information on physical environments, AR makes it possible for people to interact with design features as if they were part of the real world. This project discusses recent developments in AR technologies, highlighting their application in interior design. It discusses markerless AR methods, mobile-based simultaneous localization and mapping (SLAM) algorithms, and real-time product visualization, all which play an essential role in improving design accuracy and user interactivity. These technologies allow for a more intuitive and immersive design process, where users are able to visualize furniture, decor, and layouts within their actual living environments prior to making any buying decisions or modifications. Important apects of the paper are the exhaustive overview of AR-based modelling of furniture to help users simulate the placement of virtual furniture on actual surroundings based on accurate scaling and positioning. Moreover, research on incorporating adjustments of lighting levels to support real-looking visualizations so that one can personalize interior design solutions depending on the environments has been researched. The paper also explores usability issues of AR-based interior design applications, including depth perception, object interaction, and application scalability. In addition, the paper analyzes the shortcomings of existing AR systems in terms of real-time performance, the necessity of high-performance mobile devices, and support for a broad variety of design styles.

Keywords: Augmented Reality, Interior Design, Markerless AR, SLAM, Real-Time Visualization.

1. Introduction

Interior design has historically been concerned with the creation of functional and beautiful spaces through balancing factors like architecture, furniture, and decor. [3] Although these methods have worked, they tend to incorporate lengthy processes like hand sketches, physical material sampling, and repetitive client approvals. These are exacerbated by the problem clients have in accurately visualizing the final product, often resulting in expensive changes during execution [1]. In addition, the traditional method of interior design tends not to take dynamic elements such as light variations, space dimensions, and individual-specific customization into account, all of which have the potential to dramatically alter the end result. Clients and designers also tend to encounter issues regarding communication, as static 2D plans and simple 3D representations lack the ability to adequately express the depth and reality of a given design. This lack of interactivity limits clients' ability to engage with the design process and make well-informed decisions [5][7].

To solve these problems, sophisticated tools and techniques have been introduced step by step. Virtual tours, computer-aided design (CAD) software, and web-based design tools are some solutions [3]. These tools, however, still do not possess real-time interactivity and immersion that can completely overcome the gap between idea and execution. Hence, conventional practices are still the go-to, though they are limited [6]. The emergence of new technologies like Augmented Reality (AR) presents a revolutionary solution to these issues. AR can be used to build interactive and immersive design experiences, enabling clients to see and adjust designs in real-time. With the inclusion of features such as markerless AR, SLAM algorithms, and AI-based suggestions, these technologies hold the key to revolutionizing the interior design process, improving efficiency and user satisfaction [2][9].

In this evolving world, the need for state-of-the-art solutions that enhance visualization, communication, and efficiency is greater than ever. The intention behind this research is to explore the possibility of AR solving the age-old challenges of interior design and presenting new paths to harmonize client expectations with design outcomes and enhance the overall process.

1.1 Problem Statement

Interior design is often a slow and laborious procedure with much planning to guarantee functionality and aesthetics are both prioritized, and client requirements are met. Classic design procedures such as hand sketches, physical samples, and static 3D models are challenging for clients to visualize the end product, tending to lead to miscommunication and costly reworks. Precise measurement of spaces and experimentation with layouts or design options is tiresome and error-prone. Additionally, the available tools are not real-time interactive and fail to provide individualized recommendations,

hence making the design process inefficient and non-user-friendly. All these problems show that there is a need for innovative solutions to enhance visualization, interactivity, and decision-making to make the interior design process efficient and user-friendly for designers as well as clients.

1.2 The Role of Augmented Reality (AR) in Modern Interior Design

Augmented Reality (AR) is a new technology that enhances the real world by adding digital components (e.g., images, sound, and 3D models) to users perceptually, normally by their mobile devices (e.g., smartphones, tablets, AR glasses). As a technology, AR provides a natural, interactive, and immersive blend of the physical and virtual world. AR enables an individual to directly interact in real time with virtual furniture and change to modify and design and arrangement in his/her own room, radically altering the design experience. AR enables the interactive real-time visualization of design, closing the abstraction design to physical reality gap and forms a still more natural and interactive design process.

Application of technology into interior design significantly changed practice. Conventional interior design processes—working from scale models, hand drawings, and static 3D models may be less interactivity and immersion-focused than clients today anticipate. The processes are also labor intensive, requiring significant back-and-forth revising and rewriting based on clients' feedback, and this can cause inefficiencies and conflicting expectations. AR on the other hand, provides a remedy to these constraints in terms of real-time, dynamic alteration of design in a virtual environment, providing an interactive means of searching and altering designs prior to implementation. Clients are able to see how furniture, furnishings, and arrangements will look and feel in their own actual living spaces, minimizing uncertainty and optimizing decision-making [1][2].

In addition, AR makes design more precise by enhancing object placement and room measurement. Technology like SLAM facilitates room scanning to obtain precise space measurements and precise virtual object positioning in a room. It renders measurement error from conventional processes impossible and provides a more precise design result [6][12]. AR also possesses the capability to mimic the way the lighting conditions would influence the look of materials, textures, and color in an environment in order to enhance the simulation of the design prior to its realization. The feature ensures that the client is satisfied with the result as the final product can be viewed under different environmental conditions [4].

The partnership of Artificial Intelligence (AI) and AR also makes interior designing easier. AI is used to scan the user's sense of taste, space size, and design preference in order to give personalized design recommendations. This intelligent system can suggest suitable furniture, colors, and floor layout based on the user's sense of taste and space size to enhance user experience in the designing process as much as possible in terms of efficiency and personalization to individual needs [6][16]. This personalization facet allows AR apps to go beyond visualization, making them intelligent design tools that support designers and clients in making rational choices.

In summary, AR is increasingly a crushing force to revolutionize the interior design world. It provides visualization, real-time interaction, precision in design, and tailored advice, which accelerates the process of design, making it faster, more convenient, and interactive. Through AR integration with AI and other breakthrough technologies, interior design is revolutionizing.

1.3 Scope of the Research

The focus of this study is on the use of AR technology in residential interior design. The study will target mobile-based AR systems since these facilities have become readily available and user-friendly to designers and clients alike [7][12]. Mobile AR apps enable users to engage with design objects directly within their own environments, offering a more natural and engaging experience than conventional approaches [2]. The research will examine the potential of markerless AR, which does away with the requirement for physical markers, and the application of Simultaneous Localization and Mapping (SLAM) algorithms to facilitate precise room measurement and object placement. SLAM technology makes it possible to map and track the environment in real time, improving the accuracy of AR visualizations [6][12].

It will further examine how AR can reproduce diverse lighting conditions and create shadows in real-time to project a true representation of the end product in various environmental states [4]. This capability is necessary for replicating realistic visualizations and ensuring designs appear natural under various lighting conditions. Through simulating how light behaves when it hits materials and colors within a room, AR can assist clients and designers in making more informed decisions about where to place furniture and decor.

Moreover, the study will evaluate the incorporation of recommendation systems powered by AI in AR apps. AI has the capability to determine user interests, room sizes, and design objectives to provide customized furniture, layout, and color scheme suggestions, which make the design experience personalized for consumers [6][16]. The systems can assist designers and customers in choosing the best designs that suit the space available and the personal tastes of the clients, making the overall design process optimized.

The research will analyze both the usability and efficacy of AR-based tools in enhancing the user experience through interactive design modifications and alleviating typical pitfalls like inaccurate spatial measurements and poor visualization [5][9]. With real-time modifications, AR tools facilitate the design process, where users can inter- act with the design elements directly in their context and make immediate changes. However, its scope will remain within the sphere of domestic or residential space alone, barring considerations in business establishments or major scale architectural practice. Although the investigation will investigate AR's possibility for improving numerous attributes of interior designing, it would not research another developing technology in the field in the forms of virtual reality (VR) and mixed reality (MR), for these rep- resent specialized technologies having respective applications and interaction systems [12].

2. Literature Survey

Table 1: Literature Survey

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps
1.	Innovations in Interior Room Design using Markerless AR Mobile-based SLAM [1]	Rohman, A.T.and Romli, M.A.	*International Journal of Computer Applications,2023*	The system employs markerless AR technology and mobile-based SLAM algorithm to position virtual pieces in real-time. SLAM follows the device's location in the room to position furniture and accessories with precision without physical markers.	SLAM greatly enhanced virtual object placement accuracy in dynamic environments, supporting greater user interaction and experience with room design.	The testing was constrained to small environments, impairing the performance ability to measure under various surface conditions.
2.	Inter AR: Interior Decor App Using Augmented Reality Technology [2]	Moares, R., Jadhav, V., Bagul, R., Jacbo, R., and Rajguru, S.	*International conference on Cyber Security and Privacy in Communication Networks, 2020*	Implemented an augmented reality app for interior design, utilizing smartphone-based AR tools.	It shows how AR can enhance user experience in home decoration by providing real-time placement of virtual furniture in physical spaces	Provides limited dataset for furniture and interior objects.No integration with real-time lighting adjustment or user-generated models

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps

3.	The Usability of Mobile Application for Interior Design via Augmented Reality [3]	Shari, A.A., Ibrahim, S., Sofi, I.M., Noordin, M.R.M., Shari, A.S., and Fadzil, M.F.B.M.	*IEEE, International Conference on Recent Advances and Innovations in Engineering (ICRAIE), 2021*	Evaluated a mobile application for interior design using AR through user testing, used ADDIE process.	Focused on usability and user satisfaction enhancing visualization and decision-making in interior design.	This concentrates only on selected or small environments.Provides limited customization options.
4.	Shedding Light on Cast Shadows: An Investigation of Perceived Ground Contact in AR and VR[4]	Adams, H., Stefanucci, J., Creem-Regehr, S., Pointon, G., Thompson, W., and Bodenheimer, B.	*IEEE Transactions on Visualization and Computer Graphics, 28(12), 2021*	Used methods like OST AR, VST AR to analyse the shadows of the objects.	Cast shadows significantly improved the perception of virtual objects being in contact with the ground.	Focused primarily on visual perception without exploring the effects of varying lighting conditions or dynamic scenes in real-time AR applications.
5.	Visualization of Furniture Model Using Augmented Reality [5]	Vaidya, G.M., Loya, Y., Dudhe, P., Sawarkar, R., and Chanekar, S.	*IEEE,International Conference on Computational Intelligence and Communication Technologies (CCICT), 2022*	The system used three-dimensional solid modeling and allowed users to place and manipulate virtual furniture models in real-time	The system provided an interface for users to place furniture models in real-world spaces with accurate color and texture representation.	Limited dataset for furniture models,lack of feature like size manipulation(Not much effective).

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps
6.	Interactive Interior Design Using Augmented Reality and 3D Modeling[6	S. T. R., Santhosh, A., Ajith, A., and Gopi, A.	*IEEE,International Conference on Intelligent Cyber Physical Systems and Internet of Things (ICoICI), 2024*	Uses 3D modeling, SLAM, and LIDAR for enhanced object detection and placement. Used tools like Blender for modeling and real-time rendering on mobile devices.	Real-time, accurate furniture placement in dynamic environments using LIDAR and SLAM.	Computational challenges in mobile devices when using LIDAR and complex 3D models.
7.	Real-Time Image Placement Using Augmented Reality on Mobile Devices [7]	Agarwal, R., Varshney, N., and Aggarwal, G.	*IEEE, International Conference on Contemporary Computing and Informatics (IC3I), 2023*	The system used wall detection algorithms to accurately place and adjust virtual images in the real world.	Real-time image placement with accurate wall detection and adjustment capabilities.	It focuses on wall detection for image placement.No integration with other AR features like object scaling or 3D model placement.
8.	Real-Time Product Visualization using Augmented Reality [8]	A. Kumar, M. Kumari	*IEEE, International Conference on Innovative Sustainable Computational Technologies*	Used AR for real-time product visualization, leveraging cloud and smartphone technology for 3D object rendering and interaction.	Demonstrated the use of AR in visualizing 3D objects in real-time, showing that AR can enhance user interaction and decision-making.	It is not much user friendly and limits the modifications such as texture, space visualization.

			(CISCT), 2022			

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps
9.	Augmented Reality Based Furniture Application [9]	Gubbala, S.B., Alti, D.N., Srividhya, S.R., and Pothumani, S.	*International Conference on Applied Artificial Intelligence and Computing (ICAAIC), 2023*	Used Google AR and Android Studio. Integrated 3D product visualization tools, pricing modules, and enhanced rendering.	Improved user confidence in selecting furniture by enabling real-time visualization of models within their intended space with Google AR.	3D models are not much realistic and positioning the objects is not accurate.
10.	Reification of Furnishings for Interior Design Using Augmented Reality[10]	El-Abbasay, A. and Ibrahim, A.	*Journal of the ACS Advances in Computer Science, 14(1), 2023*	Used markerless-AR and SLAM for corner detection and real-time object placement with 3D interior modeling	Improved the user experience by enabling precise placement of virtual objects The system ensured real-time interaction.	Surface recognition is not accurate with uneven surfaces.

3. Technologies Used

3.1 Markerless AR

Markerless AR is a major technology leap in augmented reality technology, enabling virtual items to be embedded in real-world contexts without the use of physical markers [1]. Markerless AR differs from conventional marker-based AR systems in that it relies on the camera, sensors, and processing power of the device to dynamically detect and track the environment. This offers more freedom, as virtual objects may be positioned anywhere in space, which is especially beneficial in-home interior design where freedom of object positioning is central [7]. Driven by Simultaneous Localization and Mapping (SLAM) algorithms, markerless AR integrates data from multiple sensors to monitor the device's position and create a map of the surroundings in real-time. This guarantees that virtual furniture and decorative items stay correctly anchored in the desired space, irrespective of user movement or alterations in perspective, increasing realism and delivering a more immersive design experience [7][12].

One of the main benefits of markerless AR in interior design is its intuitive user experience. Users can visualize furniture and decor accurately aligned with the real world by simply pointing their mobile devices at a room.[8] This precision in scaling and positioning, driven by advanced depth-sensing technologies, allows users to confidently experiment with different furniture arrangements and design elements in real-time [6].

Additionally, markerless AR is adaptable to various lighting and environmental conditions, ensuring that virtual objects look realistic in both well-lit and dimly lit spaces.

This adaptability enhances its practicality across different home environments, maintaining a consistent visual experience without the need for special setup or environmental adjustments [4][9].

Another key advantage is the reduced setup time. Traditional AR solutions often require the placement of physical markers, which can be time-consuming [7]. Markerless AR removes this need, making the technology more user-friendly and accessible, especially on mobile plat- forms. This simplification helps designers and clients save time and focus more on creativity and decision-making [1].

In summary, markerless AR offers a revolutionary and useful solution to interior design through enhanced visualization, easier decision-making, and increased user engagement. As the technology advances further, it will be expected to play a central role in influencing the future of residential design by providing realistic, interactive, and customizable solutions.

3.2 Simultaneous Localization and Mapping

Simultaneous Localization and Mapping (SLAM) is a key technology in augmented reality (AR) applications, especially interior design, where spatial precision and dynamic interaction are required [12]. SLAM allows devices to comprehend and rebuild their surroundings in real time by localizing themselves in the space at the same time and building a precise map of the environment. This double use is provided through a mixture of data from cameras, inertial measurement units (IMUs), and depth sensors, making SLAM a pillar for markerless AR applications [1][7].

SLAM, when applied to interior design, enables proper measurement of spaces and object positioning without the need for physical markers [8]. It is able to capture space features including walls, furniture, and floors and enables the system to position virtual objects in exact positions. For instance, a user creating their living room can utilize an AR app that runs on SLAM to view furniture placement with precision, as virtual objects fall exactly into the room's measurement and current decoration. This functionality dispenses with the guesswork commonly linked to conventional design practice and improves overall user experience [6][9].

SLAM excels in dynamic spaces since it is capable of adapting to variations in the user's view and sustaining virtual object stability [1]. This makes sure that virtual models are accurately located as the user navigates within the space or changes their device's orientation. For interior design, this implies that users are able to walk around a room and see their designs from different angles, having a complete idea of the spatial organization and look [12]. Furthermore, SLAM supports advanced features such as AR-based room scanning and real-time updates to virtual designs. It allows AR systems to incorporate lighting conditions and cast shadows realistically, further enhancing the immersion and realism of the visualization. By integrating SLAM, AR tools can offer unparalleled precision and flexibility, empowering users to make informed design choices quickly and efficiently [4][9].

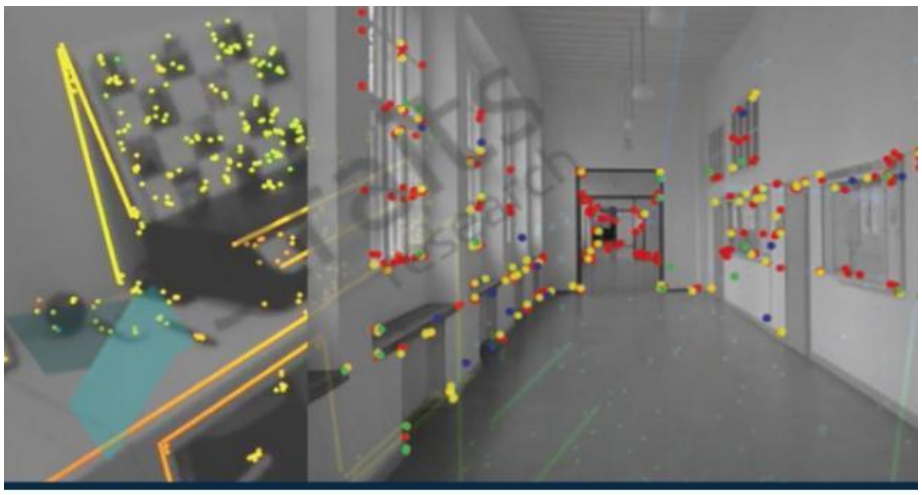

Fig. 1: SLAM Working [10]

3.3 3D Modeling and Rendering

3D modeling and rendering are central technologies in AR-based interior design, allowing the development of realistic virtual furniture, decor, and layouts. 3D modeling is the process of creating virtual objects with modifiable attributes like size, texture, color, and material. Software such as Blender, Unity, and Autodesk Maya are commonly used to create detailed models, with some using photogrammetry to create precise 3D representations from

images [5][6]. Procedural modeling methods are also utilized to automate the process of generating complicated structures, providing flexibility and accuracy [15].

The process of rendering enhances 3D modeling by adding elements such as realistic lighting, shadows, reflections, and textures on models to make them more visually realistic and attractive. Eevee, Cycles, and Unity's HDRP are some of the rendering engines which facilitates real-time rendering to allow users to view adjustments to the designs in real-time format. The technologies can also simulate environmental lighting conditions for example daylight or artificial lighting to provide a realistic simulation of how designs will look for various conditions. [4][15].

In AR applications, rendering and 3D modeling are combined to deliver an interactive design experience. People can upload pictures of furniture or decor, automatically create 3D models, and see how they look in their rooms. Collections of pre-made objects make usability even more efficient, enabling easy experimentation with layout and style [6]. Such technologies enhance spatial visualization and accuracy and hence become unavoidable in AR-based interior design [5][19].

3.4 Lighting Simulation and Shadow Rendering

Lighting simulation and shadow rendering are critical parts of AR-based interior design since they can present furniture and decor realistically in different lighting conditions. Proper lighting simulation allows users to estimate how natural daylight, artificial lighting, or a combination of both will affect the atmosphere of a room. Technologies such as Unity's HDRP and Unreal Engine utilize sophisticated algorithms to mimic real-world lighting behavior, elevating the realism of virtual spaces [4][15].

Shadow rendering also contributes to realism by establishing depth and context within AR scenes. Accurate shadow rendering establishes object placement, size, and spatial relationships and makes the transition from virtual objects to the physical world seamless[1].Markerless SLAM (Simultaneous Localization and Mapping)-based AR systems combine these elements with the ability to dynamically adapt lighting and shadows based on user viewpoint and environmental modifications[6].

In addition, AR apps integrate the use of such features as soft shadows, occlusion effects, and global illumination to simulate the complex behavior of light in real-time. Shadows cast by virtual objects, for example, vary according to changing times of day and light intensity, enabling users to see their designs in several scenarios. Other studies have noted how precise rendering of shadows enhances user perception of depth and reality, enhancing the believability and interactivity of AR visualizations [4] [10].

Through the delivery of realistic lighting and shadow effects, AR-based interior design software enables users to make effective decisions, such that designs are both aesthetically satisfactory and functionally effective under a variety of conditions[6][19].

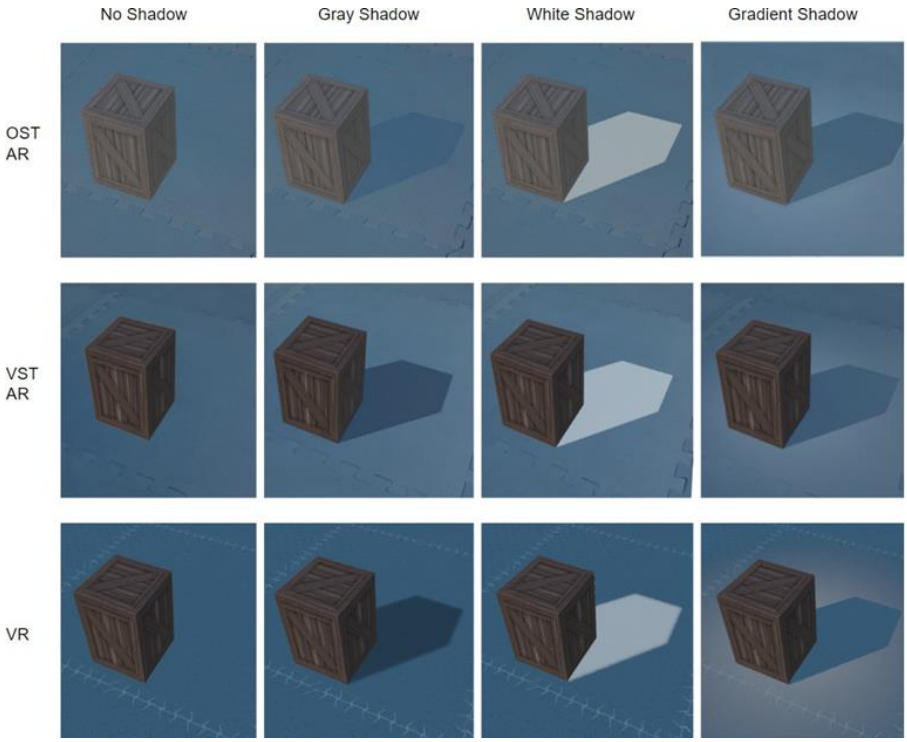

Fig. 2: Shadows cast under different conditions [4]

4. Evaluation Metrics

The assessment of AR-based interior design software can be systematically analyzed using a variety of metrics measuring different dimensions of user interaction and system performance. These metrics play a crucial role in determining how effective AR software is in facilitating immersive and effective interior design experience. The below metrics are the most important metrics for assessing such systems' performance:

1. **Usability**

Usability is an inherent measure that reflects how easily users can engage with the AR app. It involves how smoothly the users are able to use the virtual items and shift among various design variations. Commonly used metrics in evaluating usability include the completion of tasks, rates of error made when placing objects, and the level of user satisfaction. SUS and questionnaires are some common methods that collect quantitative and qualitative data on the experience of the users [6][7].

2. **Accuracy of Spatial Measurements**

Accuracy is a key consideration in AR-based interior design, especially in systems that use markerless tracking or SLAM algorithms [5]. The capability to precisely track and position virtual objects in the real-world environment is quantified through measures such as positional accuracy, measurement error rates, and alignment with real-world dimensions. These measures are essential for guaranteeing that users can attain a realistic visual layout of the interior [1].

3. **Realism and Visual Quality**

Visual quality is also a key measure of determining the success of AR in interior design. It measures the correctness of textures, lighting effects, and shadow rendering employed to render virtual objects [6]. High-quality visuals enhance the level of immersion, and measures such as rendering speed, frame rates, texture clarity, and shadow accuracy are typical measures used to determine visual realism. Subjective ratings from user opinion are commonly blended with these objective scores to assess overall quality of visual output [4].

4. **User Interaction and Engagement**

The effectiveness of user interaction within the AR environment is measured by metrics such as responsiveness, intuitiveness, and the ease of manipulating virtual objects. User interaction time, the frequency of interactions, and feedback gathered from users about the AR controls provide insights into how engaging the system is. Metrics related to gesture controls and touch-based interactions are crucial in assessing the system's design for real- time manipulation of interior elements [7].

5. **System Performance**

System performance metrics target the technicality of AR application performance in terms of processing rate, latency, and stability. A system performing at an acceptable level would achieve consistent frame rate, fast rendering times, and effective utilization of memory and processing resources. Average frame rate, per-frame rendering time, and virtual environment load times are all typically measured to assess system efficiency [4][15].

6. **User Satisfaction**

User satisfaction is a subjective but important measure in assessing AR-based tools. It is measured by conducting surveys, interviews, or the use of feedback forms that gauge the overall experience of the user with the system. High user satisfaction means that the AR tools are properly designed and effective in fulfilling the demands of users as far as functionality, ease of use, and the aesthetic appeal are concerned. This measure is important in gauging the potential for adoption of AR-based interior design solutions [10].

These measures give a complete structure for evaluating the performance of AR-based interior design systems. By employing a mixture of subjective and objective information, researchers and developers can learn about the strengths and weaknesses of such tools, facilitating ongoing improvements in user experience and system functionality.

5. Results and Discussions

The use of Augmented Reality (AR) in interior design has shown high gains in terms of visualization, interactivity, and user-driven customization. AR technologies allow users to position furniture and decor virtually within their own homes, such that they can see actual designs in real-time [5]. This enables the reduction of the big constraint of conventional interior design, where customers cannot visualize suggested layouts. Markerless AR systems, and especially those with Simultaneous Localization and Mapping (SLAM) algorithms, have played key roles in maintaining accurate object positioning and room size measurements. The technologies eliminate the need for physical markers, therefore enhancing the versatility and usability of AR applications in various environments [1][7].

one of the most impressive advantages of AR-based interior design applications is that they can replicate the real-world lighting and shadow, and even temperature conditions, in order to reflect a realistic model of the finished design. It has been of immense use and popularity among the users as this enables them to analyze how various design components are going to look in varied surroundings. Yet, issues like spatial mapping inaccuracies and a demand for better lighting simulations in low-light or highly reflective environments are areas to be worked on [4][8].

Interactivity is another aspect where AR apps are superior. Resizing, repositioning, and material customization features enable users to try out different design configurations dynamically. Such interactivity has been found to enhance user engagement and satisfaction since it enables them to have a hands-on experience designing their environments [6]. Nevertheless, usability studies reveal that certain users, especially those who are not conversant with sophisticated technology, experience difficulties in navigating AR app interfaces. Streamlining user interfaces and adding exhaustive tutorials may enable these obstacles to be overcome [3] [9].

The incorporation of Artificial Intelligence (AI) in AR platforms has further improved their functionality. AI-based recommendation systems utilize user preferences, room size, and design objectives to offer customized recommendations. Such recommendations simplify the decision-making process and are generally appreciated by users. Periodic failures on the part of AI in matching suggestions with user expectations reflect the necessity of smarter algorithms that can read subtle preferences and contextual cues [8][10].

Technically, performance reviews indicate that contemporary mobile gadgets can typically support AR applications efficiently, particularly those designed for mobile systems. Nevertheless, power-hungry capabilities like the display of high-definition 3D models or dynamic lighting simulations can tax device processing capacity and battery life, even on older or less capable devices. Optimizing these applications for a broader hardware set remains a priority [5][12].

While these technologies have improved significantly, AR interior design apps do not scale as well as integrate with other technology. While AR performs best within the domestic environment, its integration into large-scale or commercial environments is yet in its beginning phases [16]. Merging AR with augmenting technologies like Virtual Reality (VR) and Mixed Reality (MR) can potentially extend even further user experience and the usage of such technologies. Demand is evident for even more all-encompassing systems incorporating a combination of AR, AI, and other pioneering technologies [13][15].

6. Challenges and Limitations

Augmented Reality (AR) application in interior design is very challenging and fraught with many challenges and limitations which need to be fulfilled to effect successful implementation [5].Spatial mapping as well as precisely placing objects continue to remain an uphill task as environmental conditions such as dim lights, reflective materials, or obstructions could upset the functioning of SLAM algorithms to trigger misalignment and inaccuracies in measurement [1]. Furthermore, the use of cell phones also presents hardware limitations, as lower-performance or older devices might not be able to render high-quality 3D models, real-time light simulations, and interactive features, leading to a poor user experience [3][12]. Usability is also a barrier to wider adoption since the complexity of certain AR applications can drive away non-technical users [9]. Even though mobile-based AR platforms are more accessible, their functionality still demands devices with adequate processing power and compatibility, which may not be available everywhere [8]. Accurate lighting simulation and shadowing are critical for realistic AR experiences, but simulating complicated lighting situations in real-time is technically difficult, particularly in variable lighting or reflective

environments, which can diminish the realism of visualizations [4].

The use of AI-based recommendation systems, by increasing personalization, is one such area to be concerned with. Such systems rely on precise data analysis and can sometimes run counter to specific user preferences or design objectives and thus restrict creative freedom and input from users [8][10]. Additionally, even though AR does well in homes, its replication for larger and more intricate commercial spaces is something that still requires improvement. More extensive environments require sophisticated systems and cooperative capabilities that existing AR solutions are frequently not designed to support [15][16].

Creating AR apps also comes at a high expense and long timescales, since making precise 3D models, applying algorithms, and accommodating device compatibility need considerable resources. Such financial and time limitations might limit the dissemination of cheap AR solutions to smaller businesses or individuals [9]. Finally, privacy and regulatory issues exist with the data capture that comes from AR apps, like taking photographs or videos of physical environments. Developers should comply with legal requirements to protect the privacy rights of users [12].

Overall, while AR holds transformative power in interior design, overcoming these obstacles ranging from technological constraints to regulatory issues is essential for broad-based adoption and impact. Technological advances, increased usability, and regulatory acceptance will each be important in bridging these gaps.

7. Conclusion and Future Scope

Interior design using Augmented Reality (AR) has evolved tremendously in user visualization, interactivity, and experience. The users are empowered to see, set up, and interact with virtual furniture and fixtures in real spaces using technologies like SLAM, 3D models, and real-time lighting, and the design is simple and personalized.

In spite of all its success, AR is still to encounter obstacles in the form of hardware, variations in capacity between devices, external influences, and data privacy. Up to now, AR applications are associated with home interior designing for residences but can be studied later through other studies for application in business, industry, and public buildings.

Apart from this, application of AR with upcoming technologies like Mixed Reality (MR), Virtual Reality (VR), and Artificial Intelligence (AI) can The application of Augmented Reality (AR) in interior design has been excellent on the aspects of visualization, interactivity, and user experience. AR leverages technologies like SLAM, 3D modeling, and real-time lighting to make users view, personalize, and interact with virtual furniture and accessories in actual locations and enhance design and tailor-make.

Though it has expanded, AR remains plagued with issues such as hardware, device disparity, environmental, and data privacy. AR applications are now focusing on in-home interior design, but future research can explore its application for commercial, industrial, and public areas.

Green design innovation and AR hardware-capable solutions can facilitate further development of smart, green, and highly interactive interior design solutions that also put the future of the industry on a vehicle of increased design accuracy, automation, and user experience. Shared AR uses have the potential to support intelligent designers, clients, and architects in collaborating in real time with varied locations. In addition, future advancements in technology and green design principles in AR can be adapted to intelligent, green, and highly interactive interior design solutions to map the future of the interior design profession.

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