Augmented Reality in the Interior Spaces: A Systematic Review

Majid Ahsani[1]*, Sumarni Binti Ismail[1], Ali al-Ameen[2], Maedeh Fereidooni[3], Roya Dadashzadeh[4] and Pouria Ahmadi[5]

[1]Architecture Department, Faculty of Design and Architecture, Universiti Putra Malaysia, 43000 Serdang, Selangor, Malaysia, [2]Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia, [3]Pars University of Art and Architecture, Tehran, Iran
[4]Faculty of Architecture and Urban Planning, Soore University, Tehran, Iran, [2]Faculty of Fine Arts, University of Tehran, Tehran, Iran
Corresponding Author Email: ahsani.ar@hotmail.com

Abstract
Augmented reality (AR) technology has been applied in various fields, including entertainment, real estate, and warehouse logistics. It is particularly useful in construction, and architectural fields, as it allows computer-generated graphics to overlay 3D models and data in the real world. However, research on AR in architecture and design has not received enough attention. AR technology has the potential to improve the interior environment experience by encouraging users to interact with the built space through simple mobile device use. This study aims to examine the applications, benefits, and limitations of AR in indoor environments. By using the Systematic Literature Review methodology relevant information on the subject of augmented reality application and intersection with interior spaces has been gathered. The review targeted SCOPUS indexed journal articles, using specific keywords and English search language. The search results show that 29 relevant papers were extracted, with 20 remaining after removing irrelevant or not informative articles. Augmented reality (AR) technology has shown potential in interior design and interaction, particularly in visualizing spatial relationships and dimensions. Further research could integrate spatial information, multi-user applications, and collaboration using GPS and Indoor Positioning Systems (IPS). A comprehensive review of twenty articles on AR application in interior design found that most work focuses on developing new methods or applications for AR in interior spaces. It is recommended that more research articles be focused on the potential of AR technology in the design process and user interaction with designers.
Keywords: Application Development, Construction, Interior Design, Navigation, Virtual Reality.

Introduction

Augmented reality, or AR technology has found its way into various fields including gaming, entertainment, marketing, mechanical engineering, real estate, and warehouse logistics(Caarls et al., 2009; Keil et al., 2020). It also has shown to be a powerful tool for the construction, engineering, and architectural fields because it allows computer-generated graphics to overlay three-dimensional (3D) models and data in the real world(Montero et al., 2019; Shouman et al., 2022). This allows the user to see and interact with virtual objects that are added to the real world(Phan & Choo, 2010). Augmented reality has the potential to be applied in area development, interior design, product design, medical interventions, and also in project monitoring and field construction(Caarls et al., 2009; Rankohi & Waugh, 2013). While research on AR and place has mostly focused on urban and public settings(Cirulis & Brigmanis, 2013; Graham et al., 2013; Liao & Humphreys, 2015; Tran et al., 2023), the use of augmented reality (AR) to improve the usability and interior experience of building occupants has not received enough attention(Scolere & Malinin, 2023). Since AR affects how people perceive both real and virtual information sources, research on AR in architecture and design is interdisciplinary and encompasses the fields of human factors, design, and AR technology(Kim et al., 2011).

In an attempt to improve the way people experience interior spaces, augmented reality (AR) technology is being experimented with to get people to use their mobile devices to interact with the built environment(Scolere & Malinin, 2023). Media representations, interaction tools, feedback screens, trackers, and computer units are the enabling technologies for augmented reality(Kim et al., 2011). While head-worn devices (like Microsoft Hololens) can be used to experience augmented reality, many commonplace AR technologies that allow users to interact with their physical surroundings can only be accessed through mobile devices (phone or tablet; such as IKEA Place-App)(Scolere & Malinin, 2023). Mobile augmented reality is used in architecture to design buildings in real sites, enabling designers to understand user needs and expectations through participatory approaches(Shouman et al., 2022).

The user must be the starting point for the development of the project as part of the architecture and interior design project design. However, in order to satisfy clients, it is necessary to take into account factors other than their requirements, preferences, capabilities, and limitations, as well as the technical details of the materials used in their own project design and execution(Calado et al., 2013). Since each project's user needs are thought to be distinct, they should be taken into account during the design phase to guarantee a successful project delivery(Shouman et al., 2022) It is anticipated that architecture and interior design will have more interaction with clients and professionals as a result of the introduction of new representation and visualization techniques like virtual reality (VR) and augmented reality (AR), using specialized software(Calado et al., 2013).Experiments with augmented reality (AR) technology have been conducted in an attempt to improve the interior environment experience by encouraging users to interact with the built space through simple mobile device use(Scolere & Malinin, 2023).

A crucial aspect of augmented reality (AR) is placing virtual objects in the proper location, which makes the tracking system one of the most crucial parts of the system. Augmented reality systems integrate digital information and the physical world so that the user experiences them as one(Phan & Choo, 2010). AR provides practical visualization method to

enhance the user's perception in interior design tasks(Kymäläinen, 2013). Because augmented reality can visualize a multitude of potential designs in a target room, it holds great potential for interior design(Kán et al., 2021). Even though several benefits have been addressed in research, still there are challenges and limitations to the augmented reality systems such as the inaccuracy of tracking and sensing, technical restrictions, and the limiting factors for building usable AR applications(Narzt et al., 2006). The goal of this study is to apply a systematic review methodology to examine the applications, benefits, and limitations of augmented reality in indoor environments.

Methods

The Systematic Literature Review (SLR) methodology is utilized in this research. SLR is an approach that makes it possible to address research questions and gather relevant information on a subject that satisfies predetermined eligibility requirements(Mengist et al., 2020). in this review only SCOPUS indexed journal articles on the subject of augmented reality application and intersection with interior spaces was targeted. Therefore, to obtain the relevant information, specific keywords were selected. The search language was solely English and non-English articles were excluded from the search. The keywords were searched within the titles, keywords, and abstract of the articles. The search keywords, data bases and results are demonstrated in Table 1.

Table 1
Search Filters and Results

Data Base	Keywords	Number of displayed papers	Papers related to subject
Science direct	Augmented reality AND interior Design; AR AND interior design; Augmented reality AND indoor Design;	7+20+73	7
Springer link	Augmented AND reality AND interior AND Design; Augmented AND reality AND indoor AND Design;	1000+1000	16
Sage	Augmented reality AND interior Design	4	1
JSTOR	Augmented reality; Augmented reality AND interior Design	26+103	0
MDPI	Augmented reality AND interior Design	24	2
Emerald Insight	Augmented reality AND interior Design; Augmented reality AND indoor;	2+6	1
Taylor and Francis	Augmented reality AND interior Design;	24	2
DOAJ	Augmented reality AND interior Design, Augmented reality AND indoor;	22	0
Total	-	2311	29

With the exception of those concerning architecture education, a total of 29 relevant papers were extracted. Following a thorough review, papers that were irrelevant or not informative were removed. 20 articles remained in the review after these were eliminated.

Results and Discussion

Augmented reality technology has been found to be helpful in many aspects of interior design, and interaction. Siltanen (2017) discusses the use of augmented reality (AR) in interior design, particularly for visualizing spatial relationships and dimensions. It also highlights that AR interior design applications typically involve augmenting new furniture on top of live video or photographs of the space being designed. While one of the most known usage for AR in interior spaces is its potential for interactive home furnishing(Kán et al., 2021; Togo et al., 2022), researchers around the world have investigated other uses for augmented reality in indoor environments. One of these applications is for indoor navigation and wayfinding. existing indoor navigation approaches faces some challenges such as the reliance on costly equipment infrastructure for tags and readers, and the limitations in determining the operator's viewing direction(Koch et al., 2014). Augmented reality (AR) systems can enhance spatial orientation, navigation, search processes, and decision-making in GIScience(Keil et al., 2020). AR can support navigation in complex indoor environments, particularly in smart buildings(Ayyanchira et al., 2022). It can provide contextually aware information like augmented routes and color notes, and further research could integrate spatial information, multi-user applications, and collaboration using GPS and IPS(Indoor Positioning Systems)(Kim et al., 2015; Xu et al., 2024).

Applications for augmented reality (AR) can be found in cross-platform immersive and collaborative systems(Ayyanchira et al., 2022).AR technology can be applied to furniture samples with different textures and has been used in the real world for furniture arrangement, allowing users to express their coordination(Togo et al., 2022). Moreover, in order to lessen visual distractions in work environments, augmented reality (AR) can be used to create virtual partitions and pervasive displays(Lee et al., 2022). Additionally, museums and other cultural heritage sites have been using traditional and indirect augmented reality for a while now(Gimeno et al., 2017). AR has the potential to be a narrative interface for museums as well as a tool for guided tours(Caarls et al., 2009).

A comprehensive review of twenty articles was conducted in order to analyze the data from prior research on the application of augmented reality in interior design. The articles are closely examined and their conclusions are briefly discussed in

Table 2

Brief review of previous research articles

No.	Reference	Aims and objectives	Methodology	Results
1	(Caarls et al., 2009)	The paper developed an optical see-through head-mounted display system for Augmented Reality, enhancing virtual object indistinguishability and assessing its impact on art, design, and cultural heritage projects.	The authors created a head-pose tracker for the HMD using error-state Kalman filters, combining data from an inertia tracker with visual marker data for online rendering of dynamic virtual content. The system enables online head-pose rendering of dynamic virtual content and was tested with artists, designers, and curators in art, design, and cultural heritage projects for qualitative performance evaluation.	The paper describes a head-pose tracker for the HMD that works well at 100 Hz, providing accurate orientation even when moving the head slowly. It's effective for art and design, especially in disclosing cultural heritage. The authors collaborated with artists, designers, and curators, but did not provide quantitative findings.
2	(Simon & Berger, 2011)	The paper presents an interactive method for augmented reality, combining user interaction and automated tracking/reconstruction methods to build and augment piecewise planar environments. The process involves tracking, intersection line computation, and reconstruction.	The paper discusses a camera-mouse method for user interaction to define planar regions in an image stream. It uses a fixed cursor for ray-casting selection and RANSAC matching for tracking 2-D blobs. A particle filter is used to estimate the projected intersection line between planes, enhancing detection rate and accuracy. The Levenberg-Marquardt optimization method is used to refine camera motion and plane equations in 3-D Euclidean space.	The paper discusses the successful convergence of a particle filter in cluttered interior scenes, the robustness of the Hough transform in photometric measurements, and its performance in indoor and outdoor environments.
3	(Rankohi & Waugh, 2013)	The paper is a comprehensive review and analysis of augmented reality (AR) literature for the architecture, engineering, and	The paper used a research methodology to select articles from prominent journals in the AEC industry, review and categorize them based on relevant	The paper analyzes augmented reality literature in the architecture, engineering, and construction (AEC) industry, revealing a

No.	Reference	Aims and objectives	Methodology	Results
		construction (AEC) industry. It focuses on the applications of AR technology in project monitoring and field construction.	dimensions, and identify trends. The methodology included adding new journals and dimensions, categorizing articles into case studies, experimental/empirical studies, proof of concept studies, questionnaire-based studies, literature reviews, and improvement focus dimensions.	distribution of articles by journal and year of publication, research methodology, improvement focus, industry sector, location, and future trends. It identifies the building/commercial sector with the highest number of articles, while the residential sector has the least.
4	(Kymäläinen, 2013)	The goal of the paper is to develop a science-fiction prototype known as "Dreamnesting" that showcases interior design, service design, and co-created business models by utilizing augmented reality for intelligent interior design, co-creating a platform with a human-centered user study, and improving aesthetics. The technological aim was to create interior design concepts that exploited augmented reality (AR) and 3D models.	The paper uses a human-centered design approach to study users' innovation capabilities in a complex design process. It uses participatory methods and a science-fiction prototype to explore how user-created service concepts could evolve into new service models.	The study explores the use of augmented reality and 3D models in interior design, highlighting its potential to enhance user perception. It highlights the importance of realistic lighting, furniture models, and smart database search in prototypes. The paper also presents a speculative narrative of interior design, service design, and co-created business models using science-fiction prototyping.
5	(Kuo et al., 2013)	The research aims to develop a mobile augmented reality system for indoor construction, using infrared invisible marker identification and outside-in tracking mode. The Head Marker Tracking Augmented Reality (HMTAR) system	The document does not explicitly outline the specific methods used in the development of the Head Marker Tracking Augmented Reality (HMTAR) system. The system uses an infrared invisible marker identification technique and outside-in tracking	the Head Marker Tracking Augmented Reality (HMTAR) system has shown potential for indoor augmented reality positioning. It meets above-average usability requirements and can assist designers

No.	Reference	Aims and objectives	Methodology	Results
		offers tracking, event memory, and scenario sharing.	mode to enable three-dimensional indoor positioning with high environmental adaptability.	in presenting and positioning 3D virtual objects at construction sites. The system may also aid inexperienced workers in understanding task processes or providing precise 3D location information.
6	(Caruso et al., 2014)	This paper presents a research study on developing a designer-oriented, cost-effective AR system for interior design. The research proposes an AR system for interior design in the Contract Design sector, combining marker-based tracking with commercial mobile robot tracking capabilities.	This paper presents the system's technological features, a case study, and user testing. The AR system mainly consists of two parts: the AR Interface and a mobile robot. Target users of the AR system are interior designers, who can use the AR system in their daily design practice. The case study has concerned the design process for developing a Serviced Apartment (SA) to be used as a "standard model" in the context of a project for the Contract Design sector.	The AR system was used for representation and evaluation activities, and interior designers were tested for space planning tasks. The results showed high appreciation for the intuitiveness, ease of use, and immersiveness of the system. the AR system has the potential to revolutionize design and evaluation activities.
7	(Koch et al., 2014)	The paper investigates the potential of natural markers like exit signs for augmented reality (AR) support in facility maintenance tasks. It designs experiments, evaluates results, and provides recommendations for AR configurations. The study also highlights the high potential of natural markers for indoor navigation.	The study evaluated marker detection and tracking performance in an AR environment using natural markers. The researchers varied marker type, image template size, and camera resolution to determine maximum distance and angle relative to the user. The study aimed to assess the potential of natural markers for AR-based navigation and maintenance applications.	The study evaluates natural marker detection performance under various conditions, revealing high potential for AR-based facility maintenance support. The detection rate exceeds 95%, with a frame rate of 25-30 fps, marker distance of 10m, and detection angle of 85°. Recommendations

No.	Reference	Aims and objectives	Methodology	Results
				include using strong borders, high contrast, and specific camera settings for optimal tracking.
8	(Kim et al., 2015)	The paper explores the development and implementation of an AR-based wayfinding system in a hospital setting, highlighting the potential of AR to reduce human wayfinding time and cognitive workload.	The research involved an experiment on wayfinding in a university hospital with 10 students unfamiliar with the layout. They were given a task to find the department of internal medicine and then return to their original position. The participants completed a questionnaire measuring user experience and requirements of wayfinding in complex environments, including generating environmental images, identifying information factors, understanding environmental factors, and linking environmental factors with information factors.	The paper explores the cognitive factors affecting wayfinding, the inadequacy of current aids in complex environments, and the potential of Augmented Reality (AR) to reduce cognitive workload. It presents technical details and applications of AR-based wayfinding systems, and case studies explore its benefits. The university hospital experiment revealed challenges in identifying wayfinding aid locations, understanding terminologies, and recalling information. It also highlighted the importance of direct, intuitive directional information like animated routes and arrows over arbitrary decisions and map interpretation.
9	(Siltanen, 2017)	The study explores the implementation of diminished reality in interior design, addressing challenges in scene illumination, user experience, and overlapping virtual and existing furniture.	The study employs a modular real-time pipeline to create diminished reality, removing objects from the view and introducing a novel inpainting method that adapts to scene	The study's findings include the development of a diminished reality method that produces realistic results in indoor scenes, particularly in challenging

No.	Reference	Aims and objectives	Methodology	Results
			illumination changes, ensuring visually realistic results.	illumination situations. It also addresses user experience issues and characteristics of consumer applications and real indoor scenes that affect the implementation of a diminished reality solution.
10	(Gimeno et al., 2017)	The paper proposes a solution to improve museum visitors' experience by integrating traditional and indirect augmented reality, specifically at Casa Batlló museum, which could be applied to other museums or indoor environments.	The authors created a mobile augmented guide for the Casa Batlló museum using traditional and indirect augmented reality. Traditional AR was used to enhance museum assets, while indirect AR augmented the environment. A virtual world was created using virtual cubes and real and synthetic information. Usability tests were conducted to assess visitor attitudes and behaviors.	The paper reports that an application combining traditional and indirect augmented reality was well-received by visitors, with most finding it easy to use and recommending it. The application also provided visual content, including original furniture and old building images. However, some visitors suggested improvements, such as audio synchronization and headphones comfort.
11	(Montero et al., 2019)	The paper aims to enhance the design and implementation of interactive AR experiences by integrating AR model-based techniques with the capabilities of current game engines.	The authors improved GREP game platform with AR capabilities, evaluated realism, and developed a prototype for an AR system, testing it in University Carlos III auditorium.	The paper evaluates a model-based AR approach that combines game engines with model-based techniques, revealing enhanced realism in AR experiences. The study tested the realism in real settings, revealing audience interaction with AR scene elements like occlusion, perspective, collision,

No.	Reference	Aims and objectives	Methodology	Results
				lighting, and shading. The audience enjoyed the experience, and virtual objects successfully merged with real ones.
12	(Keil et al., 2020)	The aim of the paper is to examine the effects of holographic grids in augmented reality on distance estimation and location memory in a 3D indoor scenario, as well as assessing the potential effects of holographic grids on these spatial cognitive tasks.	The study involved 40 participants, evenly distributed across grid and grid conditions, in a large room. It involved three parts: estimating distances and object location memory. Participants were in no grid or grid conditions, with the latter using a Microsoft HoloLens to project a holographic grid onto the floor. They were asked to estimate egocentric and frontal distances, memorize and recall six cylinder positions, and assess location memory performance through an encoding, distractor, and recall phase.	The study found that holographic grids improved egocentric and frontal distance estimations, with significantly lower mean errors compared to no grid conditions. However, these grids did not improve object location recall, and distances were generally underestimated, with underestimations being more pronounced in the no grid condition.
13	(Kán et al., 2021)	This paper reports on a study on the application of augmented reality to customized and interactive furniture.	A new algorithm for automated furniture arrangement, based on hierarchical rules, is integrated into an interior design system, combining it with a mobile augmented reality system for interactive design and personalized recommendations. Three user studies were conducted to explore user preferences for interactive interior design, the preference between automated and optimization-based algorithms, and the	The study evaluates a recommender system for personalized furniture design, finding it comparable to optimization-based methods in user preferences and layout generation probability. The research also investigates AR usage in interior design, indicating its potential for interactive home furnishing.

No.	Reference	Aims and objectives	Methodology	Results
			probability of sensible design generation.	
14	(Shouman et al., 2022)	The experiment evaluates the effectiveness of Mobile Augmented Reality (MAR) as a co-design tool in enhancing user involvement and understanding of design project aspects compared to traditional tools.	A mobile augmented reality application has been developed to represent and translate real project scenarios into 3D models, allowing users to study and develop in real-world scenarios. The application validates user experiences and involvement levels against existing tools. The British University in Egypt's library, was selected as a case study for a spatial arrangement experiment. The ground floor features a lobby, circulation counter, group study area, cafe corner, interactive rooms, information literacy skills, cultural events room, exhibition area, and photocopy facilities. After the experimental study, participants were asked to improve study results by responding to two survey questionnaires with co-design tools and the MAR application.	The study compared the case study using a MAR application to co-design, revealing that the MAR approach was more user-friendly and efficient. Participants could easily re-design spaces through the click and drag function, compared to the time-consuming process of drawing over drawings. The MAR application improved design interaction, communication, and understanding, enhancing user involvement in the facility design process. It is recommended to develop the existing MAR application's user interface to include more interactive features, such as creating and modifying wall shapes and materials, and allowing free-hand architectural design using drawing input.
15	(Lee et al., 2022)	The paper explores the use of midair AR surfaces as virtual partitions to reduce distractions in open-plan workspaces, examining their impact on user preferences and work performance.	The study used a multi-part activity consisting of three different exercises: an attention test, a text-editing exercise, and writing a summary after watching a video lecture, all designed to require	The study found that virtual partitions reduced surrounding awareness and distractions compared to open-plan layouts. However, cognitive failure test scores

No.	Reference	Aims and objectives	Methodology	Results
			continuous attention for approximately 40 minutes. Participants wore HoloLens for a study, viewing digital content on a physical and virtual screen.	remained unchanged. Performance was higher in physical partitions, while virtual partitions showed higher scores in summary and text-editing tasks. Sound did not significantly affect distractions. No correlation was found among preference, performance, or surrounding awareness across the three conditions.
16	(Ayyanchira et al., 2022)	The paper explores a collaborative, cross-platform immersive system for real-time communication, building navigation, and visual information exchange in smart buildings, enhancing coordination and situation awareness.	The paper explores the use of augmented reality (AR) systems to display infrastructure and information by overlaying BIM with iPad camera views. It presents a cross-platform immersive system that synchronizes user locations and vital information in real-time. A case study shows a team of two users testing the prototype in an academic building.	The paper suggests that immersive visualization enhances 3D navigation and coordination for on-site collaboration in real physical environments. A user study demonstrates its effectiveness, with feedback suggesting its potential applications in emergency services and complex environments. The system's effectiveness is supported by user feedback.
17	(Togo et al., 2022)	The paper proposes a new image retrieval method for interior coordination, focusing on furniture recognition using multi-view feature extraction and evaluation using sophisticated Japanese retail company images.	The paper presents an image retrieval method using object-based, color-based, and semantic-based features, utilizing pre-trained models and weighted parameters to calculate similarity	The paper explores the use of augmented reality in interior coordination, highlighting its application in 3D interior simulation and furniture arrangement in the real world.

No.	Reference	Aims and objectives	Methodology	Results
			between query and database images.	The proposed method outperforms conventional methods in retrieving well-coordinated datasets, even with different room types. Further evaluation by professional coordinators is needed for future studies.
18	(Scolere & Malinin, 2023)	The study focuses on interdisciplinary design of a mobile augmented reality application for a LEED-Gold academic incubator, exploring AR technologies' application in interior design. This project explores user perceptions of a contextually-situated mobile AR-application for enhanced POE survey, using user feedback and in-depth interviews.	Drawing on user feedback data, observations, and in-depth interviews of 15 building occupants, the affordances of mobile-AR for interior design was identified. A beta mobile AR-application was developed for this study as an exploratory method for delivering post occupancy evaluation (POE), paired with relevant survey questions at specific building.	The think-aloud feedback and interviews revealed how users perceived the role of technological affordances, specifically technical functionality and content features inherent to the AR interface. the research presents a framework based on affordance theory that aids in designing and analyzing hybrid spaces combining AR and interior design. these results contribute toward better understanding the affordances offered by hybridity, including how it might foster "fast" sense of place.
19	(Cesário & Nisi, 2023)	The paper explores the design of interactive experiences for teenagers aged 15-19 in natural history museums using Augmented Reality prototypes. It involves co-design sessions, testing, and findings, aiming to inform museum offerings and	The study involved 223 teenagers, 12 cultural heritage professionals, and 17 master's students, focusing on understanding teens' museum experiences, co-designing museum mobile experiences, and creating mobile interpretive exhibitions	The research suggests that augmented reality (AR) is crucial for attracting teenagers' attention, with videos featuring species in their natural habitats being a positive component. Users

No.	Reference	Aims and objectives	Methodology	Results
		museum management. The study aimed to understand the interests of teenagers in improving museum tours and how museums and curators perceive them as an audience group through a twofold approach.	through user-driven innovation, divided into seven segments.	also prefer virtual and augmented reality formats for interactive museum experiences, and map information for exhibit locations. The study emphasizes the importance of addressing teenagers' interests and needs, segmenting audiences, and providing design guidelines for teenage audiences.
20	(Xu et al., 2024)	The study investigated the impact of AR-based egocentric perspectives on indoor wayfinding performance, comparing efficiency, cognitive load reduction, and spatial awareness in a multi-story building.	The study used an AR system to create a virtual environment using Velodyne LiDAR scanner point clouds and HoloLens 2 depth camera mesh models. It conducted a wayfinding experiment with four unique conditions: "control," "route," "minimap," and "global," each presenting unique cues.	The study found that using AR-enabled egocentric cues improved wayfinding efficiency, reduced cognitive load, and enhanced spatial awareness. The global condition significantly reduced cognitive and physical load, and the global condition had the highest trust level among participants. These findings support the benefits of AR-enabled cues for indoor wayfinding.

Findings from the papers show that since 2009 almost every year at least one SCOPUS indexed journal article was published on this subject, which with the passing of the time, the number of published papers has increased. based on these articles subjects and nature, they can be divided into 4 main categories. These categories and the number of papers dedicated to the subject is presented in Table 3.

Table 3
Subject Categories and the Number of Papers on that Subject

No.	Subjects	Number of papers on the subject
1	Development of a new application/device or method for the use of augmented reality in interior spaces	8
2	Application of augmented reality in architecture and interior design	4
3	Application of augmented reality in navigation in the indoor spaces	5
4	Exploring AR experience in indoor spaces	4

The summary of papers aims and objectives based on the subject categories are presented in the Table 4.

Table 4
Augmented Reality in Design and Experiencing Interior Spaces

No.	Subjects	Aim of the papers
1	Development of a new application/device or method for the use of augmented reality in interior spaces	• *Development of optical see-through head-mounted display system for Augmented Reality.* • *Development of "Dreamnesting" prototype showcasing interior design and service design.* • *Introduction of interactive method for augmented reality.* • *Mobile AR system for indoor construction using infrared invisible marker identification.* • *Proposal of AR system for interior design in Contract Design sector.* • *Evaluation of Mobile Augmented Reality (MAR) as a co-design tool.* • *Proposal of a new image retrieval method for interior coordination.* • *Interdisciplinary design of a mobile augmented reality application for a LEED-Gold academic incubator.*
2	Application of augmented reality in architecture and interior design	• *Comprehensive review of AR literature for AEC industry.* • *Investigation of potential of natural markers for AR support in facility maintenance tasks.* • *Implementation of diminished reality in interior design.* • *Application of augmented reality to customized and interactive furniture.*

No.	Subjects	Aim of the papers
3	Application of augmented reality in navigation in the indoor spaces	• *Use of midair AR surfaces as virtual partitions in open-plan workspaces.* • *Development and implementation of an AR-based wayfinding system in a hospital setting.* • *Examination of effects of holographic grids in augmented reality.*
4	Exploring AR experience in indoor spaces	• *Integration of traditional and indirect augmented reality for improved museum visitors' experience.* • *Enhancement of interactive AR experiences by integrating AR model-based techniques with game engine capabilities.*

The method of the articles was mostly experimental and with questionnaires and interviews to confirm the findings. While papers have explored environment design, experience and navigation, most bodies of work have dedicated to developing a new method or application for use of augmented reality for interior design and experience. It is however recommended that more papers be committed to the potential augmented reality technology can have on design process and user interaction with designers. Diminished reality, exploring different lightings in real time(Siltanen, 2017), furniture designs (Kán et al., 2021; Siltanen, 2017; Togo et al., 2022) and texture selection(Togo et al., 2022), are among the subject that have been briefly discussed in previous research yet have room for further exploration. It is evident that experience and interaction with interior environments through augmented reality is under explored and need to be studied more.

Conclusion

Augmented reality (AR) technology overlays 3D models and data in the real world, enabling users to interact with virtual objects. However, AR research in architecture and design has not been adequately explored. Augmented reality (AR) technology has proven to be beneficial in interior design and interaction, particularly in visualizing spatial relationships and dimensions. AR can enhance spatial orientation perception, navigation, search processes, and decision-making. It can provide contextually aware information like augmented routes and color notes. This research uses the Systematic Literature Review (SLR) methodology to gather relevant information on the subject of augmented reality application and intersection with interior spaces. A comprehensive review of twenty articles on AR application in interior design was conducted, dividing them into four main categories: development of new applications, interior design, navigation in indoor spaces, and exploring AR experience in indoor spaces. Most articles were experimental, with questionnaires and interviews to confirm findings. Paper concludes that more research should focus on the potential of AR technology in the design process and user interaction with designers.

References

Ayyanchira, A., Mahfoud, E., Wang, W., & Lu, A. (2022). Toward cross-platform immersive visualization for indoor navigation and collaboration with augmented reality. *Journal of Visualization*, *25*(6), 1249-1266. https://doi.org/10.1007/s12650-022-00852-9

Caarls, J., Jonker, P., Kolstee, Y., Rotteveel, J., & van Eck, W. (2009). Augmented Reality for Art, Design and Cultural Heritage—System Design and Evaluation. *EURASIP Journal on Image and Video Processing*, *2009*(1), 716160. https://doi.org/10.1155/2009/716160

Calado, A. V. S., Soares, M. M., Campos, F., & Correia, W. (2013, 2013//). Virtual Reality Applied to the Study of the Interaction between the User and the Built Space: A Literature Review. Design, User Experience, and Usability. User Experience in Novel Technological Environments, Berlin, Heidelberg.

Caruso, G., Re, G. M., Carulli, M., & Bordegoni, M. (2014). Novel Augmented Reality system for Contract Design Sector. *Computer-Aided Design and Applications*, *11*(4), 389-398. https://doi.org/10.1080/16864360.2014.881181

Cesário, V., & Nisi, V. (2023). Designing mobile museum experiences for teenagers. *Museum Management and Curatorship*, *38*(3), 272-292. https://doi.org/10.1080/09647775.2022.2111329

Cirulis, A., & Brigmanis, K. B. (2013). 3D Outdoor Augmented Reality for Architecture and Urban Planning. *Procedia Computer Science*, *25*, 71-79. https://doi.org/https://doi.org/10.1016/j.procs.2013.11.009

Gimeno, J., Portalés, C., Coma, I., Fernández, M., & Martínez, B. (2017). Combining traditional and indirect augmented reality for indoor crowded environments. A case study on the Casa Batlló museum. *Computers & Graphics*, *69*, 92-103. https://doi.org/https://doi.org/10.1016/j.cag.2017.09.001

Graham, M., Zook, M., & Boulton, A. (2013). Augmented reality in urban places: contested content and the duplicity of code. *Transactions of the Institute of British Geographers*, *38*(3), 464-479. http://www.jstor.org/stable/24582460

Kán, P., Kurtic, A., Radwan, M., & Rodríguez, J. M. L. (2021). Automatic Interior Design in Augmented Reality Based on Hierarchical Tree of Procedural Rules. *Electronics*, *10*(3), 245. https://www.mdpi.com/2079-9292/10/3/245

Keil, J., Korte, A., Ratmer, A., Edler, D., & Dickmann, F. (2020). Augmented Reality (AR) and Spatial Cognition: Effects of Holographic Grids on Distance Estimation and Location Memory in a 3D Indoor Scenario. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, *88*(2), 165-172. https://doi.org/10.1007/s41064-020-00104-1

Kim, M. J., Wang, X., Han, S., & Wang, Y. (2015). Implementing an augmented reality-enabled wayfinding system through studying user experience and requirements in complex environments. *Visualization in Engineering*, *3*(1), 14. https://doi.org/10.1186/s40327-015-0026-2

Kim, M. J., Wang, X., Zhu, X., & Kang, S.-C. (2011). Augmented Reality Research for Architecture and Design. In X. W. Ning Gu (Ed.), *Computational Design Methods and Technologies: Applications in CAD, CAM and CAE Education*. IGI Global. https://doi.org/10.4018/978-1-61350-180-1.ch013

Koch, C., Neges, M., König, M., & Abramovici, M. (2014). Natural markers for augmented reality-based indoor navigation and facility maintenance. *Automation in Construction*, *48*, 18-30. https://doi.org/https://doi.org/10.1016/j.autcon.2014.08.009

Kuo, C., Jeng, T., & Yang, I. (2013). An invisible head marker tracking system for indoor mobile augmented reality. *Automation in Construction*, *33*, 104-115. https://doi.org/https://doi.org/10.1016/j.autcon.2012.09.011

Kymäläinen, T. (2013). Dreamnesting – Co-created future vision of an intelligent interior design experience. *Futures*, *50*, 74-85. https://doi.org/https://doi.org/10.1016/j.futures.2013.03.013

Lee, H., Je, S., Kim, R., Verma, H., Alavi, H., & Bianchi, A. (2022). Partitioning open-plan workspaces via augmented reality. *Personal and Ubiquitous Computing*, *26*(3), 609-624. https://doi.org/10.1007/s00779-019-01306-0

Liao, T., & Humphreys, L. (2015). Layar-ed places: Using mobile augmented reality to tactically reengage, reproduce, and reappropriate public space. *New Media & Society*, *17*(9), 1418-1435. https://doi.org/10.1177/1461444814527734

Mengist, W., Soromessa, T., & Legese, G. (2020). Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX*, *7*, 100777. https://doi.org/https://doi.org/10.1016/j.mex.2019.100777

Montero, A., Zarraonandia, T., Diaz, P., & Aedo, I. (2019). Designing and implementing interactive and realistic augmented reality experiences. *Universal Access in the Information Society*, *18*(1), 49-61. https://doi.org/10.1007/s10209-017-0584-2

Narzt, W., Pomberger, G., Ferscha, A., Kolb, D., Müller, R., Wieghardt, J., Hörtner, H., & Lindinger, C. (2006). Augmented reality navigation systems. *Universal Access in the Information Society*, *4*(3), 177-187. https://doi.org/10.1007/s10209-005-0017-5

Phan, V. T., & Choo, S. Y. (2010). Interior Design in Augmented Reality Environment. *International Journal of Computer Applications*, *5*(5), 16-21.

Rankohi, S., & Waugh, L. (2013). Review and analysis of augmented reality literature for construction industry. *Visualization in Engineering*, *1*(1), 9. https://doi.org/10.1186/2213-7459-1-9

Scolere, L., & Malinin, L. (2023). The Building That Teaches: Exploring Augmented Reality Affordances in Academic Incubators. *Journal of Interior Design*, *48*(1), 64-79. https://doi.org/10.1111/joid.12229

Shouman, B., Othman, A. A. E., & Marzouk, M. (2022). Enhancing users involvement in architectural design using mobile augmented reality. *Engineering, Construction and Architectural Management*, *29*(6), 2514-2534. https://doi.org/10.1108/ECAM-02-2021-0124

Siltanen, S. (2017). Diminished reality for augmented reality interior design. *The Visual Computer*, *33*(2), 193-208. https://doi.org/10.1007/s00371-015-1174-z

Simon, G., & Berger, M.-O. (2011). Interactive building and augmentation of piecewise planar environments using the intersection lines. *The Visual Computer*, *27*(9), 827-841. https://doi.org/10.1007/s00371-011-0556-0

Togo, R., Honma, Y., Abe, M., Ogawa, T., & Haseyama, M. (2022). Similar interior coordination image retrieval with multi-view features. *International Journal of Multimedia Information Retrieval*, *11*(4), 731-740. https://doi.org/10.1007/s13735-022-00247-4

Tran, T. T. M., Parker, C., Hoggenmüller, M., Hespanhol, L., & Tomitsch, M. (2023). Simulating Wearable Urban Augmented Reality Experiences in VR: Lessons Learnt from Designing Two Future Urban Interfaces. *Multimodal Technologies and Interaction*, *7*(2), 21. https://www.mdpi.com/2414-4088/7/2/21

Xu, F., Zhou, T., You, H., & Du, J. (2024). Improving indoor wayfinding with AR-enabled egocentric cues: A comparative study. *Advanced Engineering Informatics*, *59*, 102265. https://doi.org/https://doi.org/10.1016/j.aei.2023.102265