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The Role of Augmented Reality in Enhancing Architectural Design and Spatial Experience

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ABSTRACT

This paper presents a novel approach for building an immersive multi-modal virtual exhibit hall integrating virtual reality, augmented reality, and artificial intelligence in order to transform how people perceive art and national heritage. These days, the architecture and design sectors need more user-friendly visualization systems for effective utilization of digital information. Currently, existing constructed environments account for more than half of all building activity in the German building sector. The proposed approach integrates AR-based spatial visualization, exploration, and interactive meaning-making to enhance users' understanding of architectural and landscape spaces. A practical experiment was conducted using a portable AR system to evaluate users' experiences within an outdoor landscape architecture design. Three different exploratory scenarios were implemented, each providing varying levels of user freedom and interaction. The study assessed participants' ability to explore, interpret, and establish spatial relationships within the augmented environment. This idea was supported by a hands-on experiment that used portable augmented reality to experience an outdoor landscape architecture design while taking into account and contrasting three different exploring situations. Viewers have different combinations of levels of freedom to watch the action taken in these situations. The findings demonstrated that users saw exploration as a good thing, that they were successful in giving space meaning, and that, based on the exploratory scenario, they could accurately define the spatial linkages within the AR intervention process.

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1. INTRODUCTION

In the fields of health care, schooling, building design, and art, AR has developed into a very useful tool for integrating digital media into an actual physical area. AR gives the artist a way to produce dynamic, holistic experiences that transcend the limitations of the physical world in the context of interactive or art installation. These days, AR work enables the creation to occupy space on many dimensions, coexist within the user's actual location, and change in real-time depending on viewer position and position. AR improves audiences' ability to see and interact with artistic

information, as well as their level of emotional and cognitive engagement [1]. However, there are still a lot of issues with AR art installation design. The lack of a spatial visible feedback mechanism to provide efficient and responsive communication between the user and the installation's digital components is the biggest obstacle [2]. The system's visual response to a user's location, gestures, introductions, or closeness to digitally framed material is known as spatial visual feedback. Few [3], if any, prior studies have examined the communication loop of user impact on the digital environment, although few dealt with aesthetic design or information placement.

Because of occlusion, alignment of virtual features [4], or delays in the system's reaction, users without adaptive input are likely to become perplexed, less engrossed, or frustrated. The requirement for a system or product that offers context-sensitive, real-time, qualitative visual input that dynamically adjusts to spatial parameters like view, distance, substance type, and blockage is indicated by this gap in current work.

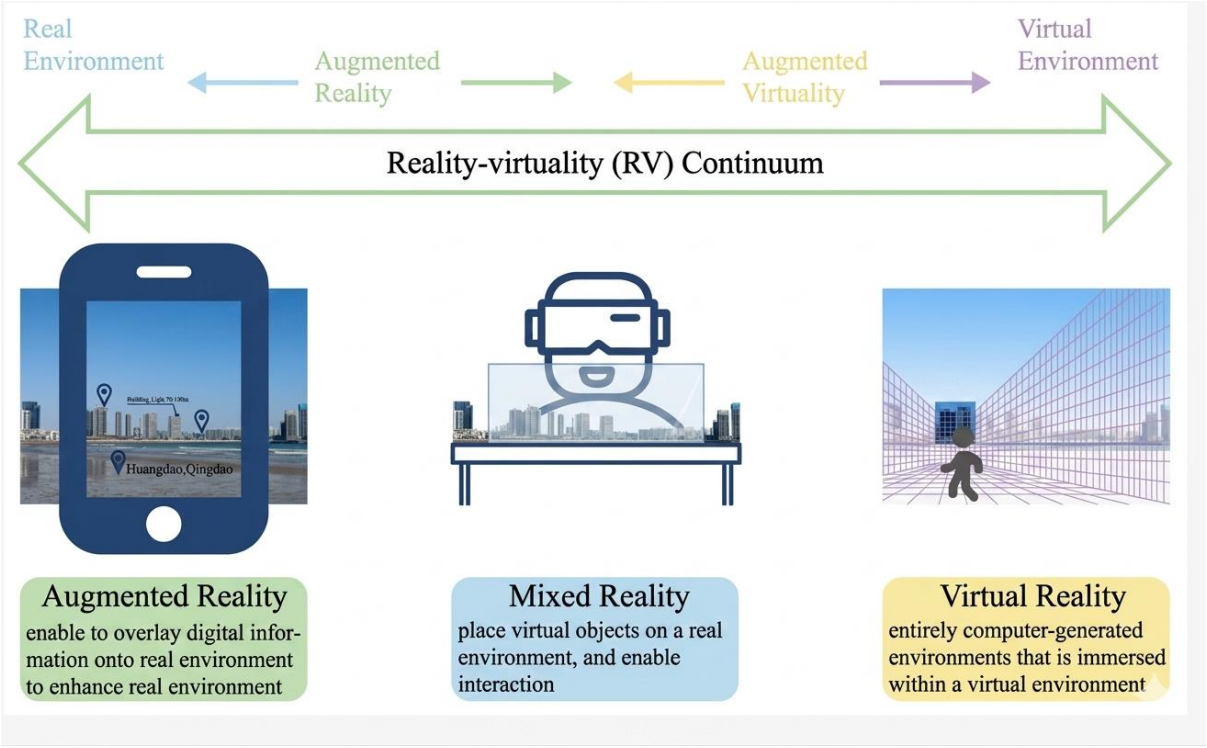

Figure 1. Concept Identification

Figure 1 shows the idea definitions. We employ extended reality technologies, such as VR, AR, and MR, in this research. Different technologies indicate different levels of environment display accuracy, according to Milgram's "reality–virtual continuity" idea. The real and virtual worlds are at each end of the continuum, while virtual reality and enhanced virtual reality are two distinct, non-overlapping realities in the middle [5].

Through realistic and engaging experiences that can be examined using Flow Theory and Embodied Cognitive Theory, the incorporation of AR and AI into apps for mobile shopping greatly increases customer engagement. This study demonstrates how AI-enhanced ARIx settings produce smooth, fully immersive, and sensorimotor-rich shopping encounters using both Flow Theory and Embedded Cognition Theory. While embodied cognition incorporates sensory-motor involvement into intellectual and emotional processes, flow arises through continuous, customized interactions

[6]. These ideas work together to explain how AI-driven augmented reality experiences improve consumer-brand relationships, boost participation, and build brand loyalty.

This work is organized so that, in Section 1, the setting and motivations for the study are presented, with the primary concern being the function of immersive technology in cultural heritage. The relevant literature is then covered in Section 2, which also highlights the problems with multi-modal platforms and virtual displays. Subsequently, Section 3 describes the particular issue and highlights the drawbacks of the existing virtual display solutions. The suggested multimodal structure, along with the procedures, information sources, and AI methods employed, are then explained in Section 4. Section 5 concludes the research by presenting the experimental results, which show how well the system works and how it might help with future advancements in virtual display designs.

2. LITERATURE REVIEW

In order to close this gap, the current study examines how ARIx qualities affect retail mobile applications, using self-brand connection and spatial immerse as mediator. Additionally, the moderating influence of visual experience on retail reputation is investigated. Data from retail customers was used to empirically test a conceptual model that was created after a thorough literature assessment [7]. The results show that through the mediated effects of self-brand connection and geographical acuity, ARIx elements in retail mobile apps improve purchasing experiences and bolster retail brand trust. Overall, the report emphasizes how important it is to use AR and AI technologies into retailing, pointing out how they can increase customer involvement and strengthen retail brand loyalty.

Using birdbath-style OST-AR glasses, this study methodically examines the effects of correlated color temperature (CCT), light intensity, and spatial lighting dispersion (i.e., wall lighting, ceiling illumination, and mixed illumination) on color differentiation ability. Three tests, each focusing on one of these three spatial illumination distributions, involved 64 people in total. Each experiment used a color discriminating task with four hues and was carried out in a controlled laboratory [8]. Fitted ellipses based on the idea of MacAdam ellipses in the CIE 1976 u′v′ color diagram were used to quantify discriminating thresholds. According to the findings, under all lighting circumstances, blue has the largest color discriminating threshold and yellow the lowest.

Convolutional Network, Bidirectional Encoder Representation from Transformers, contrast-based multimodal fusion learning, and k-Nearest Neighbors algorithms to enable contextually aware augmented reality visualization [9], adaptive personalization, semantic alignment, and smart artwork recommendations in immersive cultural contexts. For adaptive cultural material delivery and real-time customisation, a content-driven recommendation system based on k-Nearest Neighbors is used. Real-time engagement is enhanced by multimodal inputs such as voice instructions, motions, and gaze. Additionally, the technology makes multilingual cultural offerings possible, improving inclusive and accessible for many user groups.

Limited robot independence in these intricate situations frequently necessitates direct human oversight to guarantee flexibility and situational reactivity [10]. The goal of traditional remote operation systems that use VR headsets is to increase spatial awareness; nevertheless, they have constraints in their ability to perceive depth and lack proprioceptive input. By superimposing digital data directly onto the physical world, recent developments in AR, especially OST head-mounted displays, provide a more user-friendly alternative. By coordinating virtual cues with

physical actions, this method enhances egocentric spatial memory and physical coordination while lowering cognitive load and improving correctness.

Recent advances in AR, particularly optical see-through (OST) head-mounted screens, offer a more user-friendly alternative by directly overlaying digital data onto the real world. This technique improves physical synchronization and egocentric spatial memory while reducing cognitive effort and increasing accuracy by connecting virtual cues with actual behaviors. Nowadays, touch tables [11]—large horizontal touch-sensitive screens—are frequently used as a bridge between desktop-based GIS visualizations and hard copy base mapping.

While maintaining the interaction and computing benefits of digital devices over their analog predecessors, AR apps can expand on the achievement of interactive digital touch-tables by improving the visual experience. Participants in earlier digital reality studies said they felt at ease utilizing virtual reality as a tool to investigate potential future solutions. Additionally, it has been demonstrated that augmented reality's 3D exploration enhances users' spatial understanding of design interventions. In contrast to conventional printed base maps, touch tables offer a familiar interface [12]. However, they are limited in their capacity to show and control 3D data, and they can only be shared by multiple users from a single perspective. On the other hand, AR software is excellent at presenting 3D data in reality, giving each user a different viewpoint and regulate over how the data is displayed.

3. METHODS AND MATERIALS

3.1 Cognitive Space

The APA defines spatial cognition as a branch of cognitive psychological study that examines "how people gain and apply information regarding their surroundings to decide where they are [13], how to access basic necessities, and how to find their way back home." From birth, our observations shape our spatial awareness, which in turn shapes how we see and engage with the environment.

Sight accounts for 80–85% of vision, normal learning, mental processes, and conversations with our environment, despite the fact that many other senses are also engaged. Children's spatial cognition begins with sight [14], but when their motor skills—such as crawling and walking—develop, they reach a higher level of cognition. Children are able to engage with individuals, places, and objects more freely thanks to this new capacity for inquiry. This allows them to get a deeper understanding of their surroundings and the affordances of doing so. A park becomes a location where individuals may go with their pets to stroll or climbing trees, and if playground area exists, children think they can play and engage with friends. In higher levels of spatial awareness, spaces acquire meaning and become places. We can develop a better grasp of spatial arrangements and the relationships between items and people, carry out activities, and communicate throughout and around our setting through increasingly sophisticated stages of discovery [15], which entail the use of senses in addition to the ability to travel.

3.2 Possible use of augmented reality for senior citizens

In this session, relevant publications about AR applications and concerns related to the aging population were studied in order to further focus on the prospective applications of AR for older adults. Even though there aren't many researches that use augmented reality to address the needs of older people, there have been 15 papers since 2005 that look into both AR apps and the aging population.

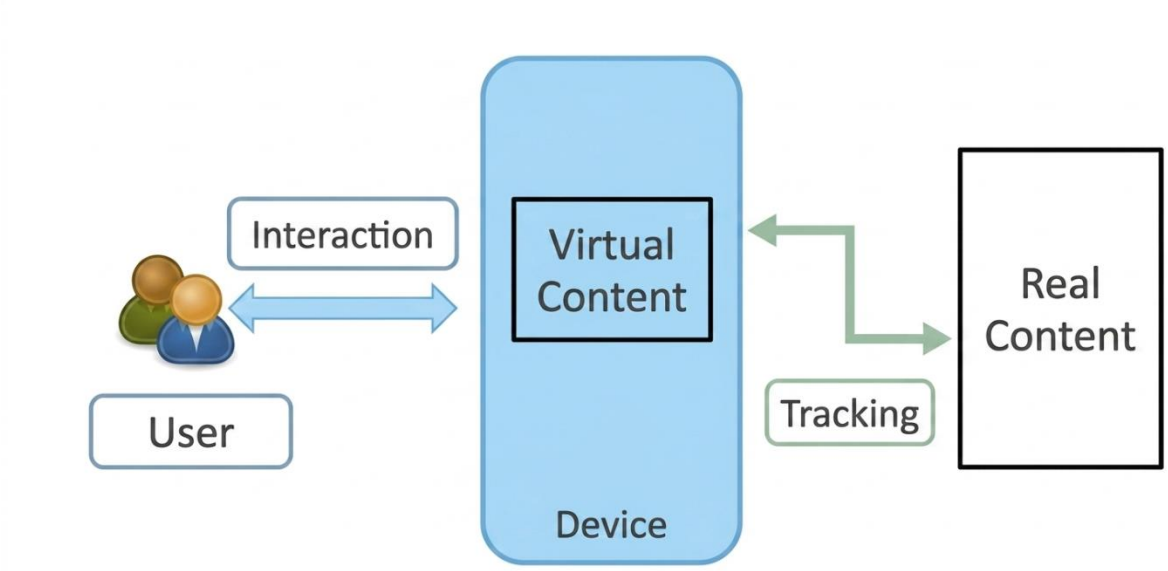

Figure 2. Proposed Augmented Reality Architecture Consisting of Six Core Components

The process of choosing, selecting, and classifying keywords is what distinguishes the Proposed Augmented Reality Architecture Consisting of Six Core Components in Figure 2 [16].

4. IMPLEMENTATION AND EXPERIMENTAL RESULTS

Sight accounts for 80–85% of perception, normal learning, mental processes, and communication with our environment, despite the fact that many other senses are also engaged. Children's spatial awareness begins with sight, but when their motor skills—such as crawling and walking—develop, they reach a higher level of cognitive. Children are able to engage with individuals [17], places, and things more freely thanks to this new capacity for inquiry. This allows them to get a deeper understanding of their surroundings and the benefits of doing so.

A park becomes a location where individuals may go with their pets to stroll or climbing treetops, and if a recreation area exists, children think that they can play and connect with friends. In more advanced stages of spatial thinking [18], spaces take on significance and become locations. We can develop a better grasp of spatial arrangements and the relationships between items and individuals, carry out activities, and communicate within and around our setting through increasingly sophisticated stages of discovery, which entail the use of senses in addition to the ability to move.

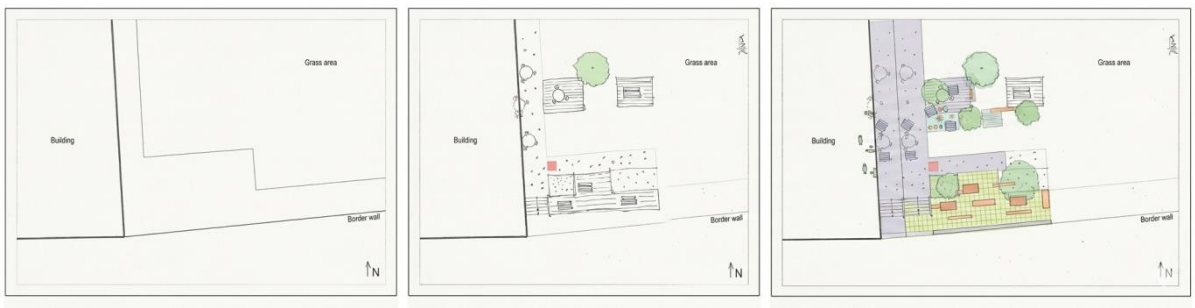

Figure 3. Analysis of plan view

To measure the total distortion in each scenario, the plan view drawings and the actual plan image of the AR interventions were compared with respect of position, form, and quantity correctness in Figure 3 [19]. The degree of liberty in each situation and the utilization of landmarks that served as referencing cues when drawing were found to be more significant than distance and spatial field.

Figure 4. The graphic data was converted into quantitative data using a rating system based on the drawings' setting, form, and amount accuracy in comparison to the actual plan view

The viewer's placement within the treatment as well as the body cues (position-movement feeling) they were able to gather while investigating the AR scenario were linked to the distortion of the drawings in its cross-section analysis in Figure 4 [20]. The precision of the drawings increased when users had more translational freedom than rotation.

Figure 5. When users were able to move through the situation, the cross section analysis revealed a better level of precision, demonstrating the importance of the body cues during translating

Based on their experiences with the AR treatment, users identified common uses and possible activities for the survey of users' opinions of the device itself, the findings of the results of the survey revealed favorable opinions of the usage of mobile devices due to their portability, low weight, and usage ease. Due to outside settings and technological problems such shadowing, object obstruction in Figure 5 [21, 22], and differences in light comparison, among other things, negative comments about the software's effectiveness emerged during tracking and deployment of the augment.

Discussion

The outcomes of the actual practice used in this study were contrasted with two other AR-related encounters whose premises and outcomes turned out to be intriguing and useful to examine. The first hypothesis drawn from these two researches was that when users had to make judgments during navigation [23], they mostly relied on landmarks in their surroundings rather than additional sources of information like pathways or physiological sensations. However, compared to various scenarios with less body-based information input, the second study showed that body cues—more especially [24, 25], those connected to translations than to rotation movements—are essential for the development of correct cognitive maps. In terms of how people navigate and create mental maps of place, these two premises—landmarks and physical cues—are complementary rather than antagonistic. Body cues aid in path integrating and the development of cognitive maps by estimating our body's location in place. In addition to visual data like optic flow, information is obtained through internal sensations that gauge our speed, speed, or rotational rotation.

5. CONCLUSION

Determining the fundamental ideas in spatial thinking that are impacted by the use of portable AR was one of the main objectives of this study. The use of mobile AR to visualize a landscape architectural design has been found to affect users' spatial cognition in a number of ways. This study took into account aspects of user movement, dimensional perceptions, and understanding. These elements encompass a wide range of users' spatial experiences and impact various sub processes of spatial cognition at varying degrees. In particular, it has been determined that, in the context of landscaping, handheld AR influences spatial cognition in three ways: first, by giving space meaning, enabling people to comprehend and see new potential uses through 3D models. Second, by allowing the spectator to move and encouraging inquiry, body cues can be integrated into a spatial encounter. Thirdly, by impacting the user's spatial imagery and

comprehension of things and their spatial relationships, which modify their spatial mental operation.

The results of applying the hands-on experience to analyze and compare the effects on users' spatial perception revealed that users' self-awareness and orientation were more necessary when more degrees of freedom were permitted, but only slightly so when navigation options were limited. Technical issues in tracking and positioning the model in actual space have an impact on the procedure of spatial sense perception, which collects information. These problems cause the AR content to appear misleadingly, frequently shaking and flashing on the device's screen. These technical issues included several hardware and software shortcomings for which there is now no conclusive fix for its application in outdoor operations. Even though these technical flaws existed, they did not prevent the AR physical activity's spatial linkages from being understood.

All of the suggested scenarios offered a variety of degrees of flexibility for the investigation of the AR intervention. Although the ability to move while seeing the overlaid space was acknowledged as a benefit of augmented reality, users most frequently requested rotation as an essential and valuable feature, even though translating and rotating are two distinct forms of moving. The panoramic views it offers, which seem to provide a better awareness and knowledge of the viewer's position in space, are the reason for this preference over rotating motions. The performance of the various vision-based method scenarios supports this assertion; while creating a plan view for the AR intervention, the one with 360° of freedom achieved the highest global accuracy in the location, appearance, and abundance. When the identical situation produced the smallest precision in its cross-section drawing, a dichotomy emerged, highlighting the importance of body cues during translational motions rather than rotational ones, which improves distance estimate when navigating the AR space.

Therefore, it is concluded that the presence of actual objects that served as markers and landmarks for the standardized observers, as well as the viewer's position in relation to the intervention, were more important factors in producing optimal outcomes in terms of spatial comprehension than more degrees of autonomy. Future research in this field is necessary to determine which variable or variables are more pertinent than the others, both theoretically and empirically, with a broader sample size and a control group using traditional media like plans and 2D visualizations, because of the intricacy factors associated with findings and the small size of the study group.

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