Integration of AR and VR into Architectural Design and Spatial Solution Verification Processes

[1] Uliana Hrechka
[1] Master's Degree (Architecture and Construction), Project Architect, Contour Companies, 40950 Woodward Ave #300, Bloomfield Hills, MI 48304, USA

Received: 29th Oct 2025 | Received Revised Version: 20th Nov 2025 | Accepted: 28th Nov 2025 | Published: 13th Dec 2025

Volume 07 Issue 12 2025 | Crossref DOI: 10.37547/tajiir/Volume07Issue12-07

Abstract

Architectural design imagining has undergone a significant transformation in recent years, driven by the advent of augmented and virtual realities. The emergence of integrating AR and VR, along with the verification of spatial solutions, is generating new opportunities for real-time data visualization and smart environments. Moreover, mixed reality (MR), which combines augmented and virtual realities, forms a "trio" of technologies, each with unique capabilities and features. These high-tech tools enhance teamwork, reduce risks, and enable architects to craft more resourceful designs that align with client requirements. As augmented and virtual realities become increasingly widespread, ensuring the functionality and quality of these technologies is essential. VR and AR verification provides a means to make both augmented and virtual realities safe, user-friendly, and capable of meeting their intended purposes. Therefore, the accuracy of spatial data, which determines whether geographic analyses yield actionable insights or ambiguous results that may waste end-user resources, is critical.

Keywords: Augmented Reality, Transformative, Virtual Reality, Architecture, Complex, Mixed Reality.

Cite This Article: Uliana Hrechka. (2025). Integration of AR and VR into Architectural Design and Spatial Solution Verification Processes. The American Journal of Interdisciplinary Innovations and Research, 7(12), 48–60. https://doi.org/10.37547/tajiir/Volume07Issue12-07

1. Introduction

Architecture is a field that encompasses multifaceted areas such as science [1-3], technology, and art, designing spaces that are sustainable [1, 4-6], functional, and aesthetically pleasing. Nevertheless, augmented and virtual realities are currently transforming how architectural designs are visualized and presented [7-9]. Recently, AR and VR have modernized the sector, providing novel tools that assist both architects and clients in interacting with, visualizing, and experiencing architectural designs in ways that were not possible before (Figure 1) [10-14].

Figure 1. Images Displaying Virtual Reality
Source: author's own development

These innovations are transforming the way architects operate, enhancing collaboration, improving how clients comprehend projects [2, 15-17], increasing accuracy, and enriching the overall design experience. Virtual Reality

(VR) refers to a computer-generated simulation of a three-dimensional (3-D) environment, which can be interacted with using specialized equipment such as VR gloves and headsets [18-21]. In contrast, Augmented Reality (AR) overlays digital information onto the real world, thereby augmenting the user's perception of their surroundings [9, 22-25]. Space, also known as spatial computing, is one of the trending advancements, encompassing a range of technologies developed to integrate virtual and augmented reality experiences [26-30]. In spatial computing, a digital note can be positioned on a real-world wall for days without any alteration or damage to the note [31-32], demonstrating persistence. The integration of both AR and VR, together with spatial solution verification, is generating new opportunities for real-time data visualization and smart environments (Figure 2).

Figure 2. VR and AR in Architectural Design and Spatial Verification
Source: author's own development

Furthermore, the convergence of augmented and virtual realities creates "Mixed Reality" (MR), which can seamlessly combine the real world with virtual objects [33-37], while allowing smooth transitions between full immersion and augmented perception. Its application in the architecture sector is transforming the field, offering enhanced visualization, client engagement, safety, collaboration, cost efficiency, sustainability, training, standards compliance, and a promising future for outsourcing architectural tasks [38, 39]. The use of spatial analysis in architectural design dates back to the early 20th century, when architects incorporated approaches such as urban planning and site assessment into their designs [2, 40]. Since then, spatial analysis has advanced considerably, driven by technological innovations and the development of novel tools and methods.For instance, integration is applied during the design stages of large-scale municipal developments, where VR is used to generate an immersive representation of the planned environment [41-44], enabling stakeholders to navigate and explore the space as if it were physically built. This immersive scenario is complemented by AR applications, which allow the overlay of design features, construction stages, and real-time data onto the actual location. This dual approach expedites decision-making and enhances comprehension of spatial interactions and scales [46-49]. Moreover, as augmented and virtual realities become increasingly common, ensuring the functionality and quality of these technologies is essential. VR and AR verification provides a means to make both augmented and virtual realities safe, user-friendly, and capable of fulfilling their intended purposes [50-54]. Verification of spatial solutions is critical, as it helps identify and resolve issues before the architectural design is released, ensuring a high-value client experience and preventing potential health risks [55-58]. Currently, there are three main types of verification: safety, client, and technical. Architects can use analytical tools combined with user feedback mechanisms to continuously monitor and evaluate both applications and user behavior [1, 57-64].

1.1. Views

Virtual Reality creates a fully immersive, simulated environment that completely replaces the user's perception of the real world and isolates users from the physical realm. Users are entirely immersed in simulated worlds where they can manipulate objects, navigate, and interact using controllers [2-6]. This is typically achieved through devices such as PlayStation VR, tablets, AR glasses, smartphones, and Oculus Rift, which overlay graphics, data, and text onto the user's perception. Examples of VR applications include immersive virtual tours and simulations for military exercises, architecture, educational programs, engineering, or surgical training, which generate novel virtual environments for learning, entertainment, and exploration (Figure 3).

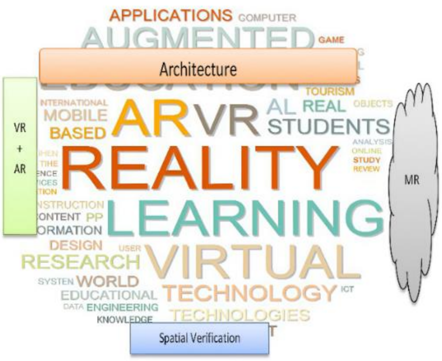

Figure 3. Learning of the Realities
Source: author's own development

The significance of VR is that it forms a virtual space where the user witnesses a diverse reality through graphic and sensory experiences. Augmented reality enriches the real world by overlaying digital data onto the physical realm. This allows users to see and interact with digital features while remaining aware of their environment, with technologies like Google Glass and smartphones. This is applied to interior design for easily visualizing furniture in offices and homes. Examples of AR are architectural visualization, AR navigation apps, and Pokémon Go.

1.2. Validation of Spatial Solutions

As these innovations continue to progress and become increasingly integrated into numerous aspects of daily activities, ascertaining the quality, user experience, and security is vital. Spatial solution is a system in which similar scenes can be recognized in an automated manner through a sequence of images [1-3]. Spatial solution is a vital feature of architectural design, permitting architects to make well-informed decisions by analyzing and understanding the spatial relationships between numerous elements of a structure or urban environment [11-14]. Spatial solution in architecture refers to the use of several approaches and devices in analyzing and understanding the spatial relationships between diverse elements of a construction, such as functional and physical characteristics of a building, urban areas, and site. To achieve success, designers use the data obtained to generate design decisions that align with human behavior, since human brains naturally perceive space, such as movement and distance, making 3D interfaces easily usable [2-5].

Validation of spatial solutions (Figure 4) is the process of ascertaining whether augmented and virtual reality use meets the expectations and requirements of its users. This encompasses a series of assessments and experiments designed to ensure that the VR/AR implementation is functional and also offers a satisfactory experience to the user. The common techniques encompass ascertaining a correspondence between certain points among sets of images, through approaches analogous to those utilized for image registration. The key issue is that outliers, that is, those that do not match nor fit the model, disturb the adjustment process called least squares, a mathematical optimization method, which provides a set of optimal pairs, such as a family of functions with independent and dependent variables.

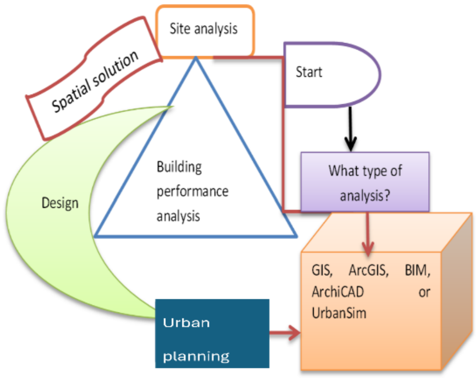

Figure 4. Exemplifies the procedure for selecting precise tools for spatial solutions
Source: author's own development

The primary aim of spatial solution verification is to identify and correct any issues or defects before releasing the application to the public [11-14]. The application of spatial verification typically involves algorithms that can identify key features such as Scale-Invariant Feature Transform (SIFT) in images. After identifying the key features, algorithms such as Random Sample Consensus (RANSAC) can be applied to ascertain the correspondence of relative positions in the images. This is indispensable in scenarios where the viewing angle might alter the appearance of the features or where objects might be positioned in multiple ways [23, 56].

1.3. Distinction Between AR and VR Technologies as Spatial Solution Factors

As technology is continuously evolving, architects are required to remain informed and continuously learn novel skills [11-14]. Augmented and virtual reality integration refers to the development and implementation of solutions that merge elements of both realities, often within a single or multiple spaces. Meanwhile, spatial solution refers to digital representation of three-dimensional (3D) space and encompasses numerous technologies such as spatial audio, augmented and virtual realities together with mixed reality (MR), computer vision, and so forth. At a fundamental level, spatial solutions generate interfaces between the physical and virtual worlds, assisting users to participate more interactively and immersively with objects and available data considerably. The advent of spatial solutions today is rooted in the innovations made in software and hardware capabilities, together with powerful processors, advanced sensors, high-resolution displays, and sophisticated input devices [41-45]. These innovations create experiences that expand the boundaries of user interfaces beyond traditional screens, then integrate the physical environment in distinctive ways.

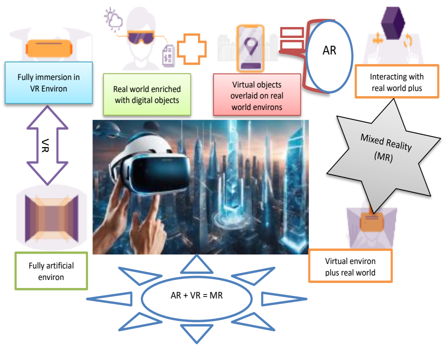

Figure 5. The Trio Hi-tech at a Glimpse
Source: author's own development

Augmented and Virtual Realities are at the pole position in spatial computing, because they are introductory features of spatial computing (Table 1).

Table 1. Concept of spatial solution and amalgamation of augmented and virtual realities: drawbacks, usage, and future

Challenges	Key Concept	Usage	Software	Future
Technical Precincts User Approval Content Formation Confidentiality and Security Concerns	Spatial scrutiny: procedure for analyzing and interpreting spatial data to derive insights	Feasibility investigation Site analysis Building performance analysis and optimization Urban planning and design	Geographic Information Systems (GIS): software environment for capturing, storing, and analyzing spatial data Spatial data: data associated with precise geographic location Building Information Modeling (BIM): digital representation of a building's physical and functional characteristics Spatial autocorrelation: evaluation of correlation between neighboring values in spatial data	Advancements in hardware Enhanced collaboration tools Artificial intelligence integration Expanding applications across industries
			Grasshopper: visual programming plugin for creating complex spatial models Ladybug: plugin for Grasshopper providing environmental analysis tools for solar radiation and wind UrbanSim: software platform for simulating and analyzing land use, urban, and transportation systems	

Source: author's own development

Both offer easy entrance to architectural firm's experts that are tapping into a worldwide talent group. Likewise lessen costs with virtual walk-throughs and models, permit collaboration, modernizing how individuals and organizations interact with digital content in the real world (Table 2).

Table 2. Do's and Don'ts of spatial solution verification

Types / Integration	Drawbacks	Benefits	Overcoming / Case Study / Devices and Advanced Tools
User Verification: focuses on ensuring that the solution meets the needs and expectations of its target users	Issues with scaling prototypes Verification cannot always be applied post-deployment Complexity of user interfaces Hardware variability causing compatibility challenges	Provides safe, clutter-free experiences Improves outcomes for specific use cases	Adopt a user-focused design approach: • Identify the desires, needs, and limitations of target users • Conduct user research • Develop and test prototypes with target users • Integrate user feedback into the development cycle • Perform iterative testing and evaluation
Technical Verification: evaluates technical aspects such as compatibility, performance, and stability	Technical limitations may affect deployment Resource-intensive testing required	Ensures reliable performance Reduces failures and downtime	Conduct rigorous testing across devices and platforms Use automated performance monitoring tools Iterate updates based on performance metrics
Safety Validation: assesses risks to the target group's mental and physical well-being, including eye strain, motion sickness, and other issues	Potential health risks if ignored Complex measurement of user responses	Protects user health Enhances user trust and satisfaction	Perform ergonomic assessments Monitor physiological responses Implement adaptive settings and warnings Iterate based on user feedback
Integration Significance: VR and AR integration offers diverse experiences; a user may start in a VR training environment and then transition to AR to apply virtual learning to real-world objects	—	—	Case Study: Simulation of passenger flow and enhancement of terminal design at Beijing Daxing International Airport, resulting in improved operational efficiency Devices and Tools: Unreal Engine, Autodesk Revit, Unity: tools for incorporating VR into architectural workflows

Source: author's own development

AR and VR enhance real-world interactions through immersive technologies; moreover, VR and AR technologies provide immersive experiences for clients, enable architects to access a global talent pool, and facilitate real-time collaboration regardless of location. By embracing these high-tech solutions, practitioners can overcome barriers and drive digital transformation.

Augmented and virtual realities are modernizing architectural design by offering immersive, collaborative, and data-rich environments. These technologies occupy a leading position in spatial computing, as they constitute foundational elements of spatial computing [42-45]. The three-tier verification system for spatial solutions (User Verification, Technical Verification, and Safety Verification) is employed to identify and address any issues or defects before releasing the application to the public [32-36].

2. Conclusion

The integration of augmented and virtual reality technologies represents a transformative shift in architectural design practice, fundamentally altering how architects conceptualize, visualize, and communicate spatial solutions. These immersive technologies have evolved from experimental tools to essential components of contemporary architectural workflows, enabling unprecedented levels of client engagement, design precision, and collaborative efficiency.

Despite the substantial benefits that AR and VR offer to the architectural profession, several challenges persist in their widespread adoption. The complexity of user interfaces continues to present barriers to seamless implementation, while issues related to scaling accuracy and technical reproducibility require ongoing refinement. Furthermore, the need for specialized hardware and software expertise demands continuous professional development and significant resource investment from architectural firms.

Nevertheless, the advantages of these technologies significantly outweigh their limitations. Virtual and augmented reality applications provide architects with the capability to create safe, clutter-free design environments that enhance visualization clarity and improve decision-making processes. The ability to conduct real-time spatial analysis and collaborative design reviews across geographical boundaries has fundamentally expanded the potential for global architectural practice. Moreover, the implementation of comprehensive verification systems ensures that spatial solutions meet rigorous safety, technical, and user experience standards before deployment.

As spatial computing continues to mature, the architectural profession stands at the threshold of a new era in design methodology. The ongoing convergence of AR, VR, and mixed reality technologies, combined with advances in verification protocols, promises to further enhance the precision, accessibility, and collaborative potential of architectural design. The future trajectory suggests that these immersive technologies will become increasingly integral to architectural education, professional practice, and client engagement, ultimately contributing to more innovative, sustainable, and user-centered built environments.

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Figure

Figure 1. Images Displaying Virtual Reality
Source: author's own development

Figure 2. VR and AR in Architectural Design and Spatial Verification
Source: author's own development

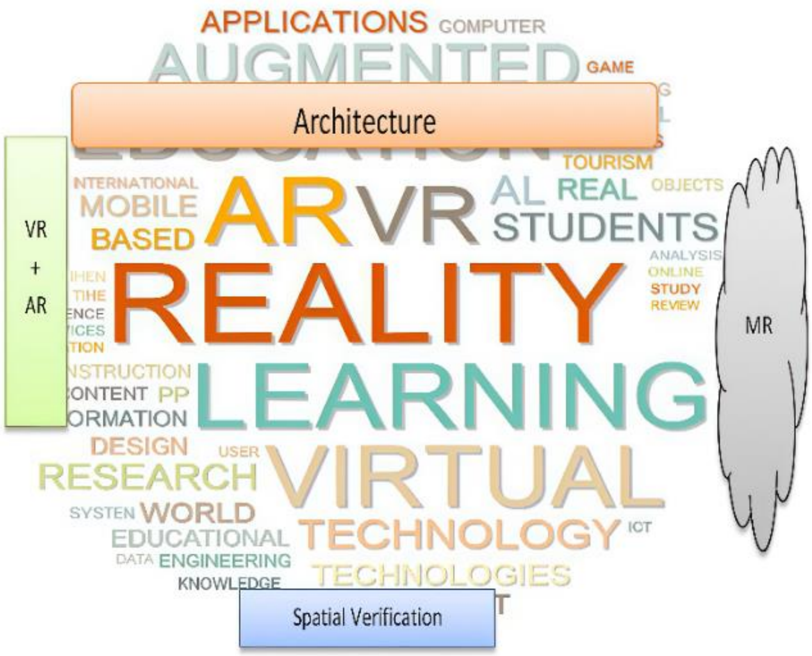

Figure 3. Learning of the Realities
Source: author's own development

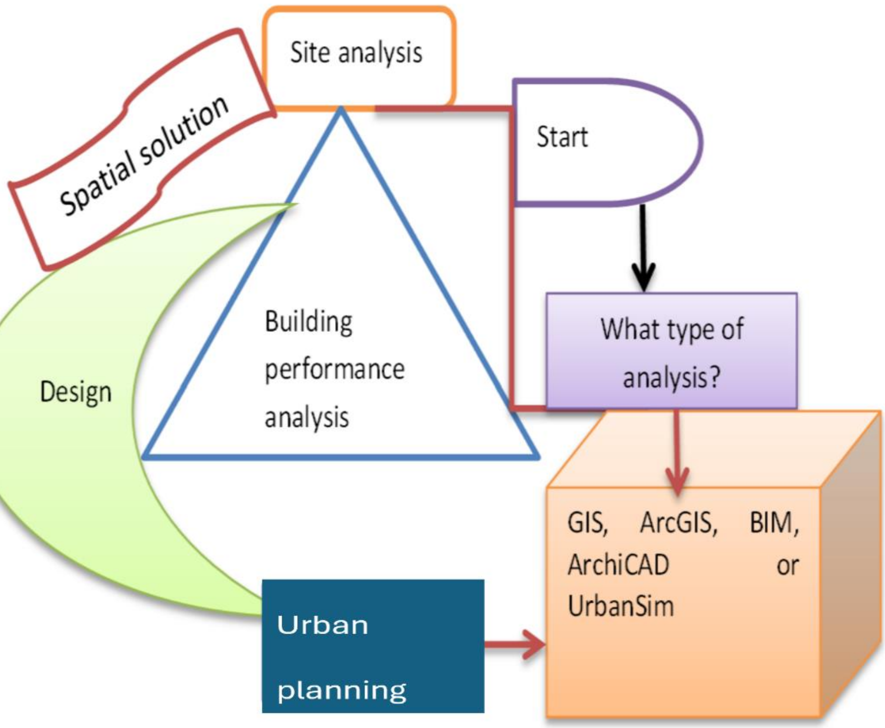

Figure 4. Exemplifies the procedure for selecting precise tools for spatial solutions
Source: author's own development

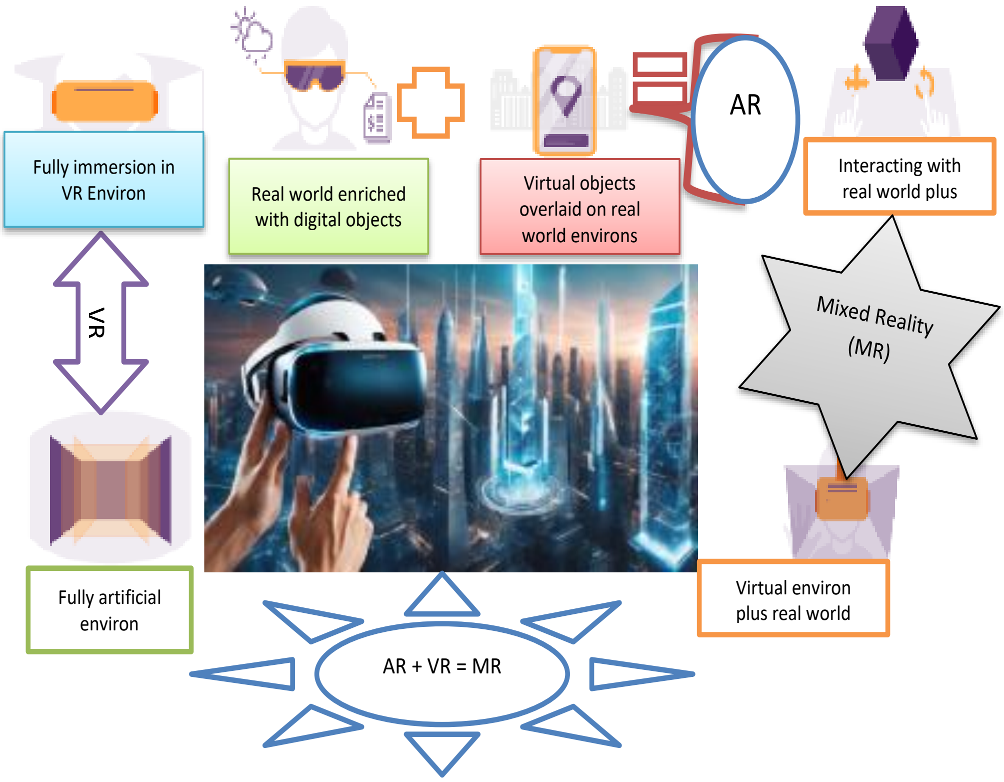

Figure 5. The Trio Hi-tech at a Glimpse
Source: author's own development