Postprint: Applications of VR and AR in Construction Engineering Informatization

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Abstract

Virtual reality, augmented reality, and mixed reality are emerging multi-dimensional visualization and communication technologies with extensive applications across various domains. Their integration with Building Information Modeling (BIM) technology in the architectural engineering field can leverage the strengths of both, creating a synergistic relationship. These technologies offer substantial value potential throughout the entire building lifecycle. This paper begins with fundamental theories and thoroughly investigates the application requirements, practical implementation models, current status, as well as future development directions and potential of this innovative fusion technology, BIMVR/AR, across the complete lifecycle—including the architectural planning and design phase, construction phase, project marketing phase, and operation and maintenance management phase. Finally, this paper analyzes the obstacles and breakthrough opportunities for further technological development.

Full Text

Preamble

Application of VR and AR in Construction Engineering Informatization

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Abstract: Virtual reality (VR), augmented reality (AR), and mixed reality (MR) represent emerging multi-dimensional visual communication technologies with broad applications across various fields. Their integration with Building Information Modeling (BIM) in the construction sector can leverage the strengths of both technologies to create synergistic effects, offering substantial

value throughout the entire building lifecycle. This paper begins with fundamental theoretical concepts and delves deeply into the application requirements, implementation models, current status, and future development directions and potential of the innovative BIMVR/AR fusion technology across all lifecycle stages, including architectural planning and design, construction, project marketing, and operations and maintenance management. Finally, the paper analyzes the obstacles and breakthrough points for further technological development.

Keywords: BIM; Virtual Reality; Augmented Reality; BIMVR; BIMAR

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1. BIMVR/AR Theoretical Foundation

BIMVR (Building Information Modeling in Virtual Reality) is a technical approach that integrates BIM (Building Information Modeling) with VR (Virtual Reality) [1]. While BIM engineers can already create highly realistic models before construction begins, current three-dimensional visualizations have significant limitations. BIM serves as a new information communication carrier in construction management, with numerous BIM-based tool software and platform applications emerging to gradually replace traditional CAD-based communication methods. VR/AR/MR technologies represent fundamentally new communication technologies, with their associated hardware and software becoming novel communication tools—the next-generation platforms for information processing and communication following computers and mobile devices.

The value potential of BIM+VR/AR/MR for the construction industry extends beyond simple upgrades to information carriers and tools; as these technologies mature, they will fundamentally transform the entire information communication paradigm. Integrating BIM with VR enables users not only to view models but to immerse themselves within them, experiencing a true sense of presence. This provides ample guidance for both designers and contractors, helping prevent numerous potential accidents and issues while making project implementation more rational. AR and MR offer similar benefits [2].

As illustrated in Figure 1 [Figure 1: see original paper], BIMVR/AR/MR is poised to become a new communication paradigm for the construction industry [3], forming an innovative technical category and interdisciplinary field. The construction industry' s productivity and informatization level have consistently lagged behind other sectors, primarily due to outdated project management and communication paradigms. The industry urgently requires newer, more efficient communication paradigms to revolutionize—or even disrupt—this massive sector.

So what specific applications does BIMVR/AR/MR have throughout the building lifecycle? The following sections provide detailed introductions.

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2. VR/AR Applications in the Building Lifecycle

2.1 Architectural Planning and Design Phase

2.1.1 BIM+VR Applications The most fundamental application of BIMVR in architectural planning and design is design scheme review. By immersing designers and reviewers in VR scenes, BIMVR achieves effects unattainable through conventional paper drawings or screen-based BIM models. The immersive nature of VR enables decision-makers and non-design professionals to participate actively and contribute evaluations. Reviewers can examine projects comprehensively from multiple perspectives—for instance, through fly-through navigation in photorealistic 1:1 BIM model scenes, providing stakeholders with a macro-level perception and judgment of future architectural planning schemes. During virtual walkthroughs, evaluators can also employ rich VR interaction methods to inspect schemes comprehensively and make localized modifications. When multiple design alternatives exist, VR facilitates intuitive scheme evaluation and comparison. Currently, numerous BIMVR software options are available for the design phase, including IrisVR, Enscape, Mars, TwinMotion, and Lumion.

2.1.2 BIM+AR/MR Applications Unlike VR, AR/MR experiences are not confined to indoor spaces but can occur anywhere, such as actual project sites. By exporting model data from BIM software, AR handheld devices and MR headsets can load models and drawings 1:1 onto the site at any location. This on-site presence enhances communication effectiveness for scheme discussions. As shown in Figure 2 [Figure 2: see original paper], BIM models can be scanned and loaded at positioning points on the project site, allowing design and review personnel to conduct AR walkthroughs using iPad devices, exploring the future completed state from any location. MR headsets function similarly, though interaction shifts from touchscreens to gesture and voice commands.

Given that ARKit and ARCore were released relatively recently and available AR/MR headset devices remain limited, few universal BIMAR/MR software solutions currently exist for the design phase. Trimble' s Sketchup Viewer for Microsoft HoloLens represents one example, enabling navigation of Sketchup models. However, most BIMAR applications remain relatively limited in interactive experience, primarily serving as custom-developed project demonstration software. For custom development, currently available tools and hardware-software platforms are shown in Figure 3 [Figure 3: see original paper].

2.2 Construction Phase

Construction management fundamentally involves applying managers' experience and skills. While traditional managers relied on paper drawings, the industry is gradually shifting toward electronic, three-dimensional model-based, and even VR/AR-enabled information media. Since construction management is essentially a continuous communication process among multiple project participants, BIMVR/AR/MR serves as an excellent communication tool with substantial application potential. BIMAR/MR is naturally suited for nearly all communication scenarios on construction sites. It is anticipated that a series of BIM- and AR/MR-based application tools and platform software will soon be developed to cover all aspects of site management.

2.2.1 BIM+VR Applications Early VR applications in construction focused on immersive experiences for engineering education and training. As training has become more widespread, simple VR experiences no longer suffice; more sophisticated applications that deeply leverage BIM and VR value are being deployed to construction sites. A common BIMVR application architecture is shown in Figure 4 [Figure 4: see original paper]. Currently, BIM+VR applications in construction primarily concentrate on safety management, quality control, progress control, and organizational coordination.

(1) Safety Management Domain
VR safety management and education represent the earliest implemented construction-phase applications. The advantages over traditional safety training are evident: workers are placed in construction scenarios to experience various safety incidents and emergency response procedures firsthand. Experiencing injuries or fatalities in VR, reinforced through visual, auditory, and haptic feedback, creates a powerful psychological deterrent. The domestic market demand for VR safety training exceeds that of foreign markets, with greater market potential. VR safety training may become standard on construction sites. Some R&D-oriented enterprises have moved beyond superficial implementations to develop software with substantial practical value for frontline workers. Taking Wanjian' s SafetyVR as an example, the experience workflow is detailed in Figure 5 [Figure 5: see original paper]. Beyond conventional safety experience items, SafetyVR incorporates several technical innovations to enhance training effectiveness: a real-name management system using ID card scanning, eye-tracking technology to accurately record assessment scores, score management and export for record-keeping (Figure 6 [Figure 6: see original paper]), and comprehensive coverage of multi-project scenarios and accident emergency categories.

Further implementation of BIMVR safety management will enable real-time BIM data import into VR scenes, automatic safety measure planning and layout, and safety calculation functions, making VR accident experiences optional rather than mandatory. As VR scenes become BIM-data-enabled and BIM scenes become VR-capable, BIM' s data value will be further extracted and

highlighted.

(2) Quality Control Domain

VR applications in quality control are primarily used for technical disclosure and training assessment, particularly for complex construction components of large projects where real-scenario training is difficult. By using BIM models to build VR scenes, setting up interaction workflows and assessment standards, training can be conducted effectively. Taking Wanjian' s SimVR Fab as an example, the typical development workflow is shown in Figure 7 [Figure 7: see original paper]. The depth of VR training disclosure depends on BIM model detail level, enabling creation of highly realistic operation workflows that replicate real scenarios. Typical experience modes include teaching mode and assessment mode. Quality disclosure and training are high-frequency tasks with daily demand from engineers and workers. Consequently, numerous BIMVR quality disclosure software solutions with simpler information interaction workflows will emerge for use by frontline BIM engineering managers. Beyond delivering VR experiences, these systems can directly export high-definition process animation videos and images (Figure 8 [Figure 8: see original paper]) for scheme archiving and other communication purposes.

(3) Progress Control Domain

Engineering progress control emphasizes pre-emptive management. Virtual Design and Construction (VDC) has become a significant academic discipline and composite professional role in enterprises. VDC engineers utilize BIM models and drawings for construction schedule virtual simulation and pre-emptive control, identifying and resolving all detectable issues before guiding actual site construction, thereby reducing uncertainties and rework costs in labor, capital, and time. For BIM engineers, simply importing their BIM models into VR scenes and precisely linking them to virtual construction timelines enables complete reproduction of future construction scenarios in a virtual environment. Managers can then rely not merely on experience but on precise data regarding materials, costs, and personnel from BIM models to optimize resource allocation curves using linear programming methods, identifying optimal construction pathways and reducing uncertainties.

The operational workflow for VR progress simulation is shown in Figure 9 [Figure 9: see original paper]. Simulation fidelity correlates with BIM model detail level. As additional information resources are integrated, more precise data-driven progress workflows become possible. After establishing progress simulation workflows, engineers can don headsets to enter VR scenes and review process details, assessing virtual construction scheme feasibility and preventing local process conflicts. As BIM and VR further converge, generalized BIMVR software will become production tools for site supervisors, material managers, and other progress-related personnel. Additionally, remote multi-user online VR experiences will become more common and practical, enabling collaborative communication among owners, contractors, designers, and supervisors within VR scenes without requiring physical presence—greatly enhancing work efficiency

and reducing communication costs.

2.2.2 BIM+AR Applications BIMAR/MR applications in construction management remain relatively uncommon, though their on-site integration advantages suggest significant potential to surpass VR applications. BIMAR/MR can be applied to safety, quality, progress, and organizational coordination domains. The communication object is no longer purely virtual BIM models but rather the interaction between BIM models and the physical site environment, involving multi-party participation rather than just managers or workers.

The BIMAR platform software development roadmap is shown in Figure 10 [Figure 10: see original paper]. Current BIMAR applications primarily develop on Apple' s ARKit interface for iOS, compatible with latest iPhones and iPads. ARCore-based Android applications remain scarce due to limited supported device models, though this will likely change as more phones and tablets support smooth AR functionality, substantially reducing AR experience costs. Current BIMMR applications mainly target Microsoft HoloLens, though the recently released Magic Leap One offers improved performance and experience, suggesting potential construction industry applications.

Taking Wanjian' s Mr.BIM as an example, BIMAR/MR applications in construction management primarily include: (1) Positioning and walkthrough: QR code-based initial positioning for BIM models (Figure 11 [Figure 11: see original paper]), AR scene navigation, and information viewing; (2) Virtual measurement and layout: Layered display of construction drawings and models, virtual layout positioning, and accurate AR measurement (Figure 12 [Figure 12: see original paper]); (3) On-site construction guidance: Installation process guidance and synchronous technical disclosure; and (4) Quality acceptance: Verification of drawings and models against physical structures to identify and record quality deviations.

2.3 Project Marketing Phase

VR/AR' s earliest construction industry applications emerged in project marketing, particularly for real estate developments where VR showrooms have become standard in many sales centers. Numerous startups domestically and internationally provide customized VR content development services for real estate marketing. VR/AR' s intuitive communication capabilities can clearly convey project features and advantages to non-professional clients in refreshing ways. For projects that have begun sales during early construction phases, BIM models imported into VR/AR engines, refined through detailed rendering and interactive programming, can accurately reproduce completed building operation states for potential customers, owners, and the public.

2.3.1 BIM+VR Applications VR applications primarily include VR showrooms, VR property displays, and VR exhibitions, presenting completed project scenes to potential clients. The typical workflow is shown in Figure 13 [Figure 13:

see original paper]. Using common VR showrooms as an example, complete VR marketing display systems typically include VR presentations for area planning, property overviews, interactive unit layouts, design concepts, furnished scenes, and home design experiences, integrated with conventional marketing content such as decoration lists, material introductions, delivery standards, and service systems. For instance, by recreating future living scenarios within buildings in VR scenes (Figure 14 [Figure 14: see original paper] shows a VR marketing case demonstrating smart refrigerator grocery shopping functions), precise marketing objectives can be achieved.

2.3.2 BIM+AR Applications AR/MR applications in project marketing are similar to VR. AR experiences typically integrate AR model display functions within mobile applications, loading models and information through QR code scanning. Image recognition-based AR experiences currently support nearly all Android and iOS mobile devices. SLAM-based AR experiences remain limited with fewer options and higher hardware requirements, making image recognition-based AR the mainstream simple application mode, such as card recognition AR model displays developed using Vuforia SDK.

Mobile AR application solutions based on Apple ARKit and Google ARCore represent the mainstream direction and hold promise for developing universal AR applications. Numerous enterprises are exploring this area, with IKEA' s AR application IKEA Place serving as a typical example. IKEA Place includes over 2,000 furniture BIM models (Figure 15 [Figure 15: see original paper]), allowing users to fully exercise their imagination in designing spaces through AR.

2.4 Operations and Maintenance Phase

Building operations and maintenance (O&M) management refers to the comprehensive management of buildings after completion and commissioning, integrating critical resources including personnel, facilities, and technology to maximize building utilization, reduce operating costs, increase investment returns, and extend building lifecycles through maintenance. During the decades-long or even century-long usage period, buildings involve operation, maintenance, and renewal. For equipment-intensive buildings such as machine rooms and factories, facility failures require immediate maintenance. However, numerous hidden works and difficulty accessing historical drawings make BIM-based VR/AR/MR applications particularly valuable.

2.4.1 BIM+VR Applications (1) Commissioning Simulation Training

During project handover and trial operation phases, BIMVR scenes can simulate operational scenarios—known as VR commissioning. For a production factory, VR can precisely simulate equipment operating conditions. Commissioning simulation content includes equipment operation condition simulation,

fire emergency drill simulation, and typical equipment failure emergency drill simulation.

(2) VR+IoT Remote Operation
Integrating VR with building facility IoT hardware enables real-time visualization of equipment operation data within VR scenes. Operators can control virtual facilities within VR scenes, with commands transmitted to actual building hardware controllers for remote control, as shown in Figure 16 [Figure 16: see original paper]. For high-risk equipment areas, remote operation in VR scenes enhances safety while remaining simple, intuitive, and convenient. Figure 17 [Figure 17: see original paper] illustrates a steel factory case where VR remotely controls machine tools. Operators holding controllers manipulate virtual equipment in VR scenes while controlling corresponding physical building equipment. Real-time facility operation data is also viewable within VR scenes, allowing operators to manage all connected equipment from control rooms.

2.4.2 BIM+AR Applications A typical case is global elevator manufacturer ThyssenKrupp' s BIM+MR O&M management system developed for Microsoft HoloLens. By networking elevator equipment data and displaying it through MR headsets, the system guides on-site maintenance personnel and improves work efficiency, as shown in Figure 18 [Figure 18: see original paper]. Upon receiving maintenance notifications, technicians open MR devices to view equipment information and fault status. During maintenance, technicians require no drawings—all model and document data is displayed in space through MR headsets, including hidden works information. For issues requiring diagnosis, remote assistance can be sought by synchronizing headset camera views with other personnel. After maintenance completion, real-time equipment operation information and work order details are viewable through MR headsets and synchronized to servers. Throughout the process, MR information augmentation assists technicians, dramatically shortening traditional drawing-, detection equipment-, and experience-based maintenance workflows and greatly improving efficiency.

Innovative BIMMR applications like ThyssenKrupp' s can be extended to all aspects of building O&M management, helping O&M personnel work efficiently. Post-completion building BIM data is updated in real-time, forming a digital virtual asset. VR/AR/MR provides management personnel and owners with media for communicating and interacting with these data assets, enabling value creation throughout the O&M lifecycle.

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3. Development Trends and Challenges

3.1 Development Trends

BIMVR/AR/MR holds critical importance throughout the building lifecycle, with potential to become 替代性或颠覆性的沟通管理技术 in communication-intensive

domains. However, the technology remains immature, requiring substantial innovative R&D and exploration for further implementation. The formation of new construction management communication paradigms will not occur overnight. The BIMVR/AR/MR development roadmap is shown in Figure 19 [Figure 19: see original paper]. For the construction industry, particularly during the construction phase, AR/MR application scenarios far exceed VR scenarios—nearly all communication needs can be addressed by AR/MR replacing traditional inefficient methods. Currently, BIMVR development has achieved certain maturity, BIMAR applications are rising, while BIMMR applications remain limited to pilot projects. As the most convenient application method, BIMMR may eventually dominate construction sites as software development costs decrease and MR hardware matures and becomes mainstream.

Following AR/MR hardware cost reductions and performance improvements, application distribution will simplify. With 5G communication technology popularization, real-time transmission of BIM model data will no longer be problematic, enabling BIMAR/MR to evolve from early standalone software applications toward cloud-based solutions where users can complete on-site communication experiences through pure Web applications—forming a small front-end (AR/MR device) and large back-end (cloud) application model. Increasing numbers of tool-level BIMVR/AR/MR software and platforms will emerge, covering various engineering subdomains, particularly those closely related to BIM model-based communication.

3.2 Obstacles and Breakthrough Points

VR/AR/MR development obstacles in construction are multifaceted: (1) The industry workforce has relatively low technical literacy, resulting in slow technology adoption; (2) Slow BIM technology development inevitably impacts BIMVR/AR/MR 普及应用; and (3) VR/AR/MR hardware technology and costs remain far from 普及应用 requirements.

Construction industry profit margins are generally low. If new technology introduction can deliver value through cost reduction, quality improvement, and efficiency gains, the entire industry will embrace it. BIMVR/AR/MR 普及应用 breakthrough points include: (1) Reduced VR/AR/MR hardware costs and improved performance; and (2) Emergence of 刚需型、易用型 BIMVR/AR/MR application software.

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