

Augmented Reality for On-Site Construction Coordination with BIM Integration

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ABSTRACT: The integration of Augmented Reality (AR) with Building Information Modeling (BIM) has emerged as a transformative approach to improving construction coordination, particularly in complex, dynamic on-site environments. BIM provides comprehensive, data-rich digital models that encapsulate geometric, material, and scheduling information, while AR overlays this virtual content onto physical construction sites through devices such as tablets, head-mounted displays, and AR-enabled helmets. This combination creates an immersive, context-aware environment that enhances design visualization, progress monitoring, and collaboration among stakeholders. On-site application of AR-BIM systems enables workers and project managers to align as-designed models with as-built conditions, thereby facilitating early detection of errors, discrepancies, or clashes between structural and mechanical systems. Such real-time visualization reduces rework, accelerates decision-making, and improves installation accuracy, particularly for mechanical, electrical, and plumbing (MEP) coordination. Additionally, AR provides interactive guidance for construction tasks, supports quality assurance by aligning real-time progress with BIM schedules, and improves safety management through the visualization of hazard zones. By enabling remote access to on-site visualizations, AR also enhances stakeholder communication, bridging the gap between design offices and field operations. Despite these advantages, challenges remain. High-fidelity AR-BIM integration requires robust data synchronization, accurate spatial tracking, and device compatibility, while issues such as model complexity, large file sizes, and hardware limitations pose barriers to widespread adoption. Human factors, including the need for worker training and acceptance, further influence implementation success. Nevertheless, ongoing advancements in cloud computing, interoperability standards, and wearable technologies, alongside the integration of artificial intelligence and Internet of Things (IoT) sensors, are expected to expand AR-BIM applications. AR-enabled BIM integration significantly strengthens on-site construction coordination, offering measurable benefits in productivity, safety, and quality. As technology matures, it promises to become an essential component of digital construction workflows.

KEYWORDS: Augmented reality, On-site construction, Coordination, BIM integration

1.0 INTRODUCTION

The construction industry is undergoing a profound transformation driven by the adoption of digital technologies that are reshaping conventional design, planning, and execution practices. Traditionally characterized by fragmented workflows, reliance on 2D drawings, and manual coordination, construction projects have historically faced persistent challenges such as cost overruns, schedule delays, and miscommunication among stakeholders (Jin and Li, 2023; Mohammedi and Arrouf, 2024). The rise of digital transformation has begun to address these inefficiencies, introducing tools that integrate information, streamline collaboration, and enhance project visibility across the entire lifecycle. Among the most significant developments are Building Information Modeling (BIM) and Augmented Reality (AR), two complementary technologies that together offer powerful capabilities for bridging the gap between

virtual models and real-world construction sites (Elshafey *et al.*, 2020; Dudhee and Vukovic, 2023).

At the center of this digital transition, Building Information Modeling (BIM) has emerged as a foundational methodology and data repository. Unlike traditional CAD systems that focus primarily on geometric representation, BIM captures and organizes multi-dimensional project information, including materials, costs, scheduling (4D/5D BIM), and facility management data (Kovacic and Honic, 2021; Yang *et al.*, 2024). By serving as a central and dynamic source of truth, BIM enables architects, engineers, contractors, and owners to work within a shared environment, thereby reducing redundancies and improving decision-making accuracy. Furthermore, the parametric nature of BIM allows for rapid scenario analysis and change management, ensuring that modifications in design are immediately reflected throughout the project (Alwan *et al.*, 2021; Haghghat and Sadeh, 2023). Its role extends beyond design and

construction, supporting operation and maintenance phases, thereby aligning with the broader concept of digital twins for lifecycle asset management.

While BIM provides the foundation for data integration and collaboration, Augmented Reality (AR) introduces a practical interface for interacting with these digital models directly in the physical job site. AR technologies superimpose virtual elements—such as BIM-generated models, annotations, or construction sequences—onto the actual environment using mobile devices, head-mounted displays, or AR-enabled helmets (Koo and O’Connor, 2022; Palma *et al.*, 2023). This capability creates an immersive and context-aware experience that allows field personnel to visualize designs at full scale, verify construction accuracy in real time, and detect potential clashes or discrepancies before they escalate into costly errors. For instance, mechanical, electrical, and plumbing (MEP) systems can be virtually aligned with the built environment, enabling installers to confirm precise positioning without relying solely on 2D plans.

The synergy between BIM and AR marks a significant step toward a more integrated, intelligent construction process (Pan and Zhang, 2023; Sepasgozar *et al.*, 2023). Whereas BIM consolidates project information into a structured and accessible format, AR ensures that this information is actionable and accessible in situ. Together, they enhance communication, improve stakeholder coordination, and reduce inefficiencies that traditionally arise from disconnects between office-based planning and site-level execution. Moreover, AR’s ability to provide interactive, real-time overlays strengthens worker training, safety visualization, and progress monitoring, thereby aligning with the construction industry’s push toward higher productivity and reduced risk (Chen *et al.*, 2021; Yazdi, 2024).

Digital transformation in construction is increasingly defined by the convergence of BIM as a data-rich central repository and AR as a visualization interface that grounds virtual information within the physical workspace (Shirowzhan *et al.*, 2020; Ceccon and Villa, 2020). This integration not only improves project efficiency and accuracy but also represents a paradigm shift in how construction teams coordinate, collaborate, and execute complex projects in the field.

2.0 METHODOLOGY

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework was adopted to ensure methodological rigor and transparency in reviewing the literature on augmented reality (AR) for on-site construction coordination with building information modeling (BIM) integration. A comprehensive search strategy was employed across multiple academic databases, including Scopus, Web of Science, IEEE Xplore, and ScienceDirect, covering publications from 2010 to 2025. The search terms combined keywords and Boolean operators such as “Augmented Reality,” “Building Information Modeling,” “BIM

integration,” “construction coordination,” and “on-site visualization.” Additional sources were identified through backward and forward citation tracking of relevant studies.

The inclusion criteria focused on peer-reviewed journal articles, conference papers, and review studies that explicitly addressed AR applications in construction with direct linkage to BIM data. Studies were included if they reported on methods, tools, case studies, or frameworks where AR was utilized for visualization, coordination, progress monitoring, clash detection, or stakeholder collaboration. Exclusion criteria eliminated articles unrelated to construction applications, studies addressing virtual reality without AR, papers lacking BIM integration, and non-English publications. Grey literature such as dissertations, project reports, and non-peer-reviewed material was excluded to ensure quality and reliability of evidence.

All retrieved references were managed using Mendeley to remove duplicates before screening. Titles and abstracts were reviewed to eliminate irrelevant studies, followed by full-text screening based on the eligibility criteria. The screening process was conducted independently by two reviewers to minimize bias, with disagreements resolved through discussion. Data extraction focused on study objectives, AR platforms and devices used, BIM integration approaches, reported benefits, challenges, and outcomes related to construction coordination.

The PRISMA flow ensured systematic identification, screening, eligibility assessment, and inclusion of relevant studies. Out of an initial pool of records, only those meeting the strict criteria for AR-BIM integration in on-site coordination were retained. The synthesized evidence provides a comprehensive understanding of how AR enhances BIM-driven construction practices, highlighting both the technological advances and the existing barriers that shape its adoption in real-world projects.

2.1 Fundamentals of AR and BIM Integration

The rapid evolution of digital technologies has transformed construction practices, shifting from traditional drawing-based workflows to data-driven and immersive methods that enable more precise planning, monitoring, and execution. At the forefront of this transformation is the integration of Augmented Reality (AR) and Building Information Modeling (BIM), which together provide powerful capabilities for connecting digital models with the physical construction site (Assila *et al.*, 2022; Bhatara *et al.*, 2024). Understanding the fundamentals of AR and BIM integration requires examining the individual technologies, their unique strengths, and the ways in which they synergistically interact to enhance construction coordination.

Augmented Reality (AR) refers to the technology that overlays digital information onto the user’s view of the real world, creating an enriched perception of the physical environment. Unlike Virtual Reality (VR), which immerses users entirely within a virtual space, AR blends physical and

virtual elements, enabling real-time interaction with both. In construction, AR is particularly valuable because it allows project stakeholders to visualize design models, annotations, and construction sequences directly on-site and at full scale (Garbett *et al.*, 2021; Safikhani *et al.*, 2022). For example, an engineer wearing AR glasses can see the intended layout of mechanical or electrical systems projected onto partially constructed spaces, ensuring correct alignment before physical installation. This capability reduces reliance on 2D drawings and abstract interpretations, thereby improving accuracy, communication, and decision-making.

AR in construction also supports interactive workflows such as clash detection, safety visualization, and progress monitoring. Workers can follow step-by-step guidance projected within their field of view, reducing the likelihood of errors and enhancing productivity. Furthermore, AR’s ability to provide real-time overlays fosters a more intuitive understanding of complex project data, enabling teams to resolve conflicts more quickly than when using conventional documents or screens (Logeswaran *et al.*, 2024; Awadallah *et al.*, 2024).

Building Information Modeling (BIM) is a process and methodology that creates and manages data-rich, parametric 3D models throughout the lifecycle of a construction project. Unlike traditional CAD systems that primarily focus on geometry, BIM integrates a wide array of information, including material specifications, structural properties, cost estimates, and scheduling data. Each element within a BIM model is an object with embedded attributes, making it not just a visual representation but also a comprehensive data repository (Qiu *et al.*, 2021; Borghoff *et al.*, 2024).

The power of BIM lies in its ability to provide a shared platform for collaboration. Architects, engineers, contractors, and facility managers can access the same model, ensuring that all stakeholders are working with consistent and up-to-date information. This reduces duplication of effort, minimizes errors from miscommunication, and supports more informed decision-making. Beyond design and construction, BIM also facilitates facility management by serving as a digital twin of the built asset, allowing operators to track performance and plan maintenance effectively (Zhao *et al.*, 2022; Tavakoli *et al.*, 2024).

The integration of AR and BIM is particularly impactful because the two technologies complement each other’s strengths. BIM provides the structured and data-rich foundation necessary for accurate design and planning, while AR transforms this static digital content into an interactive, context-sensitive experience on the job site. In this relationship, BIM functions as the backbone of data and project information, whereas AR acts as the interface through which this information is visualized and utilized in real-world conditions.

For instance, when BIM models are linked to AR platforms, construction teams can superimpose structural layouts,

installation guides, or project timelines onto the physical site. This not only allows verification of whether construction matches design intent but also helps in identifying potential discrepancies before they escalate into costly rework. The synergy also supports real-time coordination between field and office teams, as AR-enabled devices can capture site data and feed it back into the BIM environment, keeping the model continuously updated (Kim *et al.*, 2023; Awadallah *et al.*, 2024). This bidirectional flow of information is critical for advancing digital twin concepts in construction.

The practical application of AR-BIM integration relies heavily on the devices and platforms through which users interact with the technology. Several hardware solutions are currently employed in construction, each offering different advantages depending on context.

AR glasses such as Microsoft HoloLens provide immersive, hands-free experiences where BIM models can be projected into the user’s field of vision with high spatial accuracy. These devices are particularly useful for tasks requiring detailed inspection, clash detection, or collaborative visualization during design review. Tablets and mobile devices, while less immersive, offer flexibility and accessibility, making them widely adopted for quick visualization, annotations, and site inspections. They enable users to scan QR codes or markers on-site to retrieve BIM data instantly.

More specialized solutions, such as AR-enabled helmets, combine safety equipment with digital visualization, making them practical for use in active construction zones (Bodhwani and Sharma, 2023; Jaju and Sulam, 2024). These helmets integrate protective gear with heads-up displays that allow workers to view models and instructions without compromising safety. Mobile apps linked to cloud-based BIM repositories also support remote access, allowing stakeholders who are not physically present to interact with the same AR-enhanced models for coordination and decision-making.

The integration of AR and BIM represents a fundamental advancement in digital construction practices. AR brings models to life by situating them directly within the physical environment, while BIM ensures that these models are accurate, information-rich, and collaborative. Together, they form a symbiotic system that enhances visualization, coordination, and decision-making across the project lifecycle. With the increasing availability of advanced AR devices and cloud-based BIM platforms, their combined application is set to become an essential component of modern construction workflows, bridging the persistent gap between digital planning and physical execution (Diara and Rinaudo, 2021; Dahbi *et al.*, 2022).

2.2 Applications in On-Site Construction Coordination

The integration of Augmented Reality (AR) with Building Information Modeling (BIM) has opened new possibilities for on-site construction coordination, offering practical

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applications that improve accuracy, communication, and efficiency across project lifecycles as shown in figure 1. By projecting data-rich BIM models into physical job sites, AR provides context-aware visualization that bridges the persistent gap between digital planning and field execution (Kassem and Kifokeris, 2023; Bibri and Jagatheesaperumal, 2023). Its applications in construction coordination can be grouped into several key domains: design visualization and verification, clash detection and issue resolution, installation guidance, progress monitoring, and collaboration.

One of the most direct applications of AR-BIM integration is design visualization, where virtual BIM models are overlaid

onto construction sites in real time. This enables stakeholders to assess whether ongoing work aligns with the design intent and to visualize completed structures before physical construction is finalized. For example, an architect or site engineer can wear AR glasses and walk through a partially constructed building while simultaneously viewing the BIM model projected into the environment. Such visualization allows for immediate comparison between as-designed and as-built conditions, offering rapid insights into discrepancies that might otherwise remain undetected until later stages (Tran *et al.*, 2021; Son and Hung, 2024).

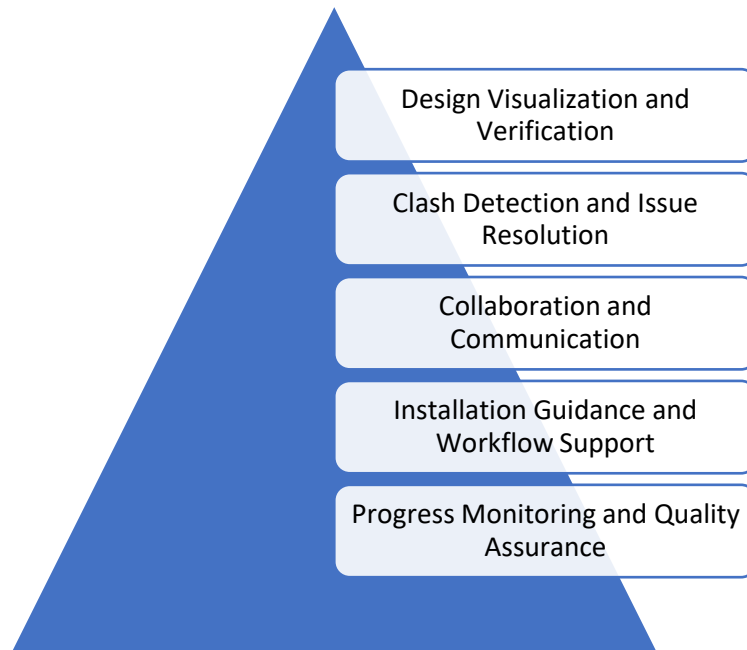


Figure 1: Applications in On-Site Construction Coordination

This early verification is particularly valuable for preventing costly rework. If a wall is incorrectly placed or structural components are misaligned, AR makes these errors visible at the point of installation, reducing downstream impacts. By enabling proactive detection of clashes and mismatches, AR strengthens quality control and ensures that construction adheres to the original design intent.

AR-BIM integration is especially powerful in addressing the challenges associated with mechanical, electrical, and plumbing (MEP) systems, which are among the most complex elements to coordinate on-site. Through AR visualization, these systems can be projected into the physical space before installation, allowing contractors to check whether ducts, pipes, or conduits interfere with structural elements or with each other.

This application greatly reduces rework, which is one of the most significant contributors to construction delays and cost overruns. By identifying conflicts at the point of execution, AR enables immediate resolution of issues, often before materials are wasted or work is carried out incorrectly. In this sense, AR acts as a real-time clash detection tool,

complementing pre-construction model coordination efforts by extending verification directly into the field.

Beyond visualization, AR serves as a practical tool for guiding installation tasks with high precision. Workers equipped with AR glasses or helmets can receive step-by-step instructions projected onto the physical environment, showing them exactly where components should be placed. This reduces reliance on 2D plans and ensures alignment of installation components with millimeter-level accuracy.

Such applications are particularly beneficial in projects that require complex assemblies, such as prefabricated components or high-tech facilities where tolerances are minimal. The integration of AR with digital twins further enhances this workflow by allowing iterative updates: field data captured through AR devices can be fed back into the BIM model, which in turn updates the digital twin of the project. This bidirectional exchange supports continuous improvement of workflows and ensures that both design and field data remain synchronized throughout construction (Raitviir *et al.*, 2024; Zhang *et al.*, 2024).

AR is also an effective tool for monitoring progress and verifying quality in real time. By capturing site data and

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overlaying it with BIM-generated construction schedules, managers can instantly evaluate whether work is proceeding as planned. For example, AR platforms can compare the current state of a site against scheduled milestones, flagging delays or deviations from expected progress.

In addition to progress tracking, AR enhances safety and compliance by visualizing hazard zones, restricted areas, or safety instructions directly in the worker’s field of view. Workers can see highlighted danger zones on the floor or receive alerts about potential risks, thereby reducing accidents and improving adherence to safety protocols. These applications support both quality assurance and safety management, two critical aspects of effective construction coordination.

Finally, AR significantly improves collaboration and communication among stakeholders. Remote participants—such as architects or project managers located off-site—can access AR-enhanced views of the construction site, enabling them to evaluate progress, provide feedback, and make decisions without being physically present. This capability reduces delays caused by travel or miscommunication and ensures that all stakeholders have a shared, up-to-date understanding of project status.

Moreover, AR allows immersive model sharing that minimizes misunderstandings often associated with 2D drawings or static 3D renderings. By providing stakeholders with the ability to “walk through” designs at full scale, AR fosters clearer communication, faster consensus-building, and more effective decision-making. This reduces the risk of disputes and strengthens overall project coordination.

The applications of AR in on-site construction coordination, when coupled with BIM, represent a transformative step in modern construction practices. From design visualization and clash detection to installation guidance, progress monitoring,

and collaborative communication, AR provides practical solutions to long-standing challenges in the industry. By projecting BIM’s data-rich models into the physical environment, AR enables real-time verification, precision alignment, safety enhancement, and stakeholder engagement (Wijerathna *et al.*, 2024; Nguyen *et al.*, 2024). As these technologies mature and become more widely adopted, they are expected to significantly reduce errors, improve efficiency, and redefine the standard for construction coordination.

2.3 Technical Considerations

The integration of Augmented Reality (AR) and Building Information Modeling (BIM) has demonstrated remarkable potential for transforming construction workflows, particularly in on-site coordination. However, achieving seamless functionality requires addressing several technical considerations that determine the accuracy, usability, and scalability of these systems (Ogunwole *et al.*, 2023; Ştefan *et al.*, 2024). These considerations include data integration, device compatibility, tracking and accuracy, interoperability, and cloud connectivity as shown in figure 2. Each represents a critical layer in ensuring that AR-BIM solutions provide meaningful value in real-world construction environments.

The foundation of AR-BIM integration lies in synchronizing complex BIM data with AR platforms in a way that preserves both accuracy and usability. BIM models are inherently data-rich, containing geometric, material, scheduling, and cost information. However, these models are often too heavy for direct use in AR applications, requiring optimization, data filtering, or conversion. Simplification techniques such as level of detail (LOD) reduction and model segmentation are often applied to ensure smooth rendering on AR devices without compromising essential information.

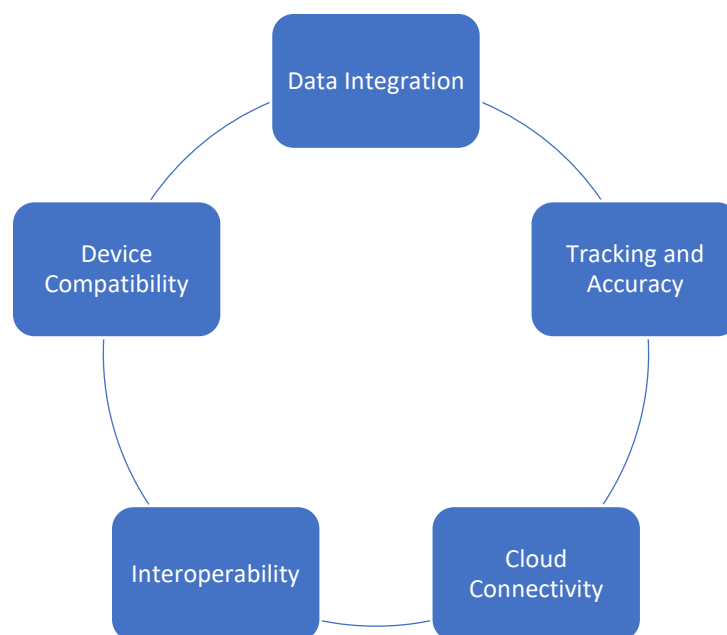


Figure 2: Technical Considerations

Furthermore, real-time synchronization between the BIM repository and AR platforms is essential. Construction sites are dynamic, and any changes in design must be reflected instantly in AR systems to avoid outdated or misleading visualizations. Achieving this synchronization demands efficient workflows for exporting BIM data into AR-compatible formats, as well as middleware solutions that act as translators between platforms. Effective data integration not only ensures fidelity of information but also guarantees that AR visualizations remain relevant and actionable on-site. The choice of hardware significantly impacts the adoption and effectiveness of AR-BIM systems. Wearables, such as Microsoft HoloLens or AR-enabled helmets, provide immersive and hands-free visualization, making them suitable for tasks requiring precision and continuous interaction with the physical environment. These devices free up workers' hands for installation tasks, enhancing safety and productivity. However, their cost, weight, and learning curve can present barriers to widespread use.

In contrast, handheld devices such as tablets and smartphones are more affordable, widely available, and user-friendly. They are often employed for quick visualization, site inspections, and issue reporting. While less immersive, they offer flexibility and accessibility that can accelerate adoption in field environments. Choosing between wearables and handhelds depends on the complexity of tasks, the level of immersion required, and the trade-off between cost and functionality. In many cases, hybrid workflows that combine both device types may provide the most effective solution.

One of the most significant technical challenges in AR-BIM integration is ensuring accurate spatial alignment between digital models and the physical environment (Sidani *et al.*, 2021; Alirezaei *et al.*, 2022). Several tracking technologies are employed to achieve this goal, each with unique strengths and limitations.

Global Positioning System (GPS) provides large-scale positioning but lacks the precision necessary for detailed construction tasks, where millimeter-level accuracy is often required. Indoor positioning technologies, such as Bluetooth beacons or radio-frequency identification (RFID), can enhance localization accuracy in confined environments, but they require additional infrastructure and maintenance.

Computer vision-based methods, using cameras and sensors embedded in AR devices, are emerging as powerful alternatives. These techniques rely on real-time scanning and recognition of physical features, enabling highly accurate alignment without the need for external infrastructure. However, computer vision is sensitive to lighting conditions, occlusions, and surface textures, requiring robust algorithms for consistent performance. In practice, hybrid approaches that combine GPS, beacons, and computer vision are often deployed to balance scale, precision, and reliability.

For AR-BIM systems to function effectively across diverse platforms, interoperability is a critical requirement. BIM relies on standardized data formats such as Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie), which enable consistent exchange of information between software systems. AR applications must be capable of reading, interpreting, and displaying this information without losing fidelity.

Interoperability also extends to ensuring that data captured in AR environments, such as progress updates or annotations, can be seamlessly reintegrated into BIM systems. Without standardization, AR-BIM integration risks fragmentation, where each solution operates in isolation, undermining the collaborative potential of digital workflows. As international standards evolve, greater interoperability will facilitate smoother integration, reduce redundancies, and promote adoption across the industry.

Cloud connectivity is another cornerstone of effective AR-BIM integration, providing the infrastructure for real-time updates and collaboration. Through cloud-based platforms, BIM models can be stored, managed, and accessed by multiple stakeholders simultaneously, ensuring that the data used in AR applications is always current. This is particularly important in construction environments, where design changes and field conditions evolve rapidly.

Cloud-based AR-BIM systems also enable remote collaboration, allowing off-site architects, engineers, or project managers to view on-site AR visualizations and provide input without physically visiting the site. This reduces delays, travel costs, and coordination challenges. Furthermore, integration with cloud services allows AR devices to capture field data—such as photos, measurements, or annotations—and upload them instantly to the shared BIM repository, maintaining a continuous feedback loop between field and office (Nguyen *et al.*, 2020; Merkert *et al.*, 2020).

The successful integration of AR and BIM in construction coordination depends on a careful balance of technical considerations. Data integration ensures that BIM's rich information can be effectively visualized in AR environments, while device compatibility determines accessibility and usability for different user groups. Accurate tracking underpins the reliability of overlays, and interoperability ensures seamless data exchange across platforms. Finally, cloud connectivity provides the foundation for real-time collaboration and continuous updates. Addressing these challenges not only enhances the functionality of AR-BIM systems but also accelerates their adoption as essential tools in digital construction workflows. As these technical foundations mature, the construction industry will increasingly leverage AR-BIM integration to achieve higher precision, efficiency, and collaboration on job sites.

2.4 Benefits of AR-BIM Integration

The integration of Augmented Reality (AR) with Building Information Modeling (BIM) represents one of the most impactful technological advancements in modern construction practices. By linking BIM’s data-rich digital models with AR’s immersive visualization capabilities, construction teams can achieve unprecedented levels of precision, collaboration, and efficiency. This integration addresses long-standing industry challenges such as rework, miscommunication, and safety risks, offering tangible benefits across the project lifecycle as shown in figure 3 (Demirdögen *et al.*, 2021; Akindotei *et al.*, 2024). The most significant advantages include enhanced accuracy and error reduction, improved productivity, better stakeholder coordination, cost savings from reduced rework, and strengthened safety management.

Accuracy is paramount in construction, where even minor deviations from design intent can lead to costly rework or

structural inefficiencies. AR-BIM integration improves accuracy by projecting BIM models directly onto the construction site, enabling real-time verification of as-designed versus as-built conditions. Workers can visually confirm the correct placement of structural elements, mechanical systems, or prefabricated components, significantly reducing the likelihood of errors during installation.

Additionally, AR facilitates early detection of design clashes and discrepancies, which are often missed when relying on 2D drawings or abstract 3D models viewed on screens. By aligning BIM data with the physical environment, errors can be identified at the point of construction rather than during later inspections, minimizing delays and avoiding compounding mistakes. This heightened accuracy translates into improved quality of construction and stronger compliance with design specifications.



Figure 3: Benefits of AR-BIM Integration

AR-BIM systems streamline workflows by providing workers with immediate access to relevant information in context. Instead of consulting paper drawings or separate digital devices, workers can receive step-by-step AR instructions directly in their field of view. This reduces time spent interpreting plans, searching for information, or clarifying tasks with supervisors.

Moreover, AR-enabled guidance supports precise and efficient installation of complex assemblies, reducing trial-and-error approaches that consume valuable time. The integration with digital twins ensures that construction data remains updated, allowing workers and managers to adapt quickly to design modifications without disrupting workflows. Collectively, these capabilities lead to higher

productivity, reduced downtime, and more predictable project schedules.

Construction projects often involve diverse teams—architects, engineers, contractors, and owners—whose effective coordination is critical to project success. AR-BIM integration enhances collaboration by offering a shared visualization environment where stakeholders can interact with models at full scale in real-world contexts. This immersive experience eliminates ambiguities inherent in technical drawings, fostering clearer communication and faster consensus.

Remote stakeholders can also benefit from AR-BIM systems through cloud-based platforms that allow them to view on-site AR visualizations from anywhere. This reduces the need for frequent site visits and accelerates decision-making. The

improved transparency ensures that all participants have access to consistent, up-to-date information, reducing the risk of misunderstandings that can lead to costly disputes.

Rework remains a persistent challenge in construction, accounting for significant cost overruns and wasted resources. Errors in installation, design misinterpretations, or overlooked clashes often necessitate tearing down and rebuilding, which is both time-consuming and expensive. AR-BIM integration directly addresses this issue by enabling real-time verification of construction against BIM models.

By detecting potential conflicts early—such as mechanical, electrical, and plumbing (MEP) systems clashing with structural components—AR allows immediate resolution before work proceeds further. This proactive approach minimizes material waste, labor inefficiencies, and schedule delays. The reduction in rework translates into measurable cost savings and improved project profitability (Khursheed *et al.*, 2024; Rasanjali *et al.*, 2024). For owners, this also enhances confidence in project delivery within budgetary constraints.

Safety is one of the most critical concerns on construction sites, where complex environments and heavy equipment pose significant risks. AR-BIM systems contribute to better safety management by visualizing hazard zones, restricted areas, and safety protocols directly in the worker’s field of view. Workers can see highlighted areas on the ground indicating fall risks or zones where equipment is operating, improving situational awareness.

Additionally, AR can be used to deliver interactive safety training, simulating real-world scenarios without exposing workers to danger. Combined with BIM’s data-driven understanding of site conditions, AR can ensure that safety plans are accurately reflected in the field. These applications reduce accidents, strengthen compliance with occupational safety standards, and foster a culture of proactive risk management.

The benefits of AR-BIM integration extend across all phases of construction, from design to execution and handover. Enhanced accuracy ensures that projects align with design intent, while productivity gains reduce downtime and accelerate completion. Improved stakeholder coordination fosters transparency and collaboration, while reductions in rework lower costs and improve profitability. Finally, the ability to manage safety risks through AR visualization further reinforces its value as a transformative tool.

As the construction industry continues to embrace digital transformation, AR-BIM integration is set to become a cornerstone of future workflows. Its ability to bridge the gap between virtual models and physical environments not only addresses current inefficiencies but also lays the foundation for more intelligent, data-driven construction practices. By combining precision, efficiency, and safety, AR-BIM integration promises to redefine how projects are coordinated and delivered in the built environment.

2.5 Challenges and Limitations

While the integration of Augmented Reality (AR) and Building Information Modeling (BIM) offers substantial benefits for construction coordination, its widespread implementation is not without challenges. Both technologies are still maturing, and their deployment in real-world construction environments highlights several technical, data-related, human, and economic limitations (Wang *et al.*, 2020; Omrany *et al.*, 2023). Understanding these challenges is essential for stakeholders seeking to evaluate feasibility, manage risks, and maximize the long-term value of AR-BIM systems.

One of the foremost technical challenges relates to hardware capabilities. AR devices such as smart glasses, AR-enabled helmets, and tablets remain limited in terms of battery life, processing power, and field of view. For instance, head-mounted displays like Microsoft HoloLens offer immersive experiences but are often bulky and may become uncomfortable during extended use on construction sites. Similarly, handheld devices provide flexibility but require constant manual handling, reducing productivity for tasks that demand hands-free operation.

Tracking accuracy also poses a critical limitation. AR-BIM systems rely on precise alignment of virtual models with the physical environment. Any tracking error—whether from GPS inaccuracy, poor beacon calibration, or computer vision limitations—can cause misalignment, undermining trust in the technology. On construction sites where precision down to millimeters is required, even small deviations can compromise installation accuracy. Furthermore, computer vision-based tracking is highly sensitive to environmental conditions such as lighting, surface texture, and occlusion. Poorly lit or cluttered environments can cause AR overlays to drift or lose calibration, reducing reliability during field operations.

BIM models are inherently complex, containing detailed information about geometry, materials, scheduling, and cost. While this richness is advantageous for planning, it presents challenges when transferring data into AR platforms. AR devices often lack the capacity to render large, high-resolution models in real time, leading to performance issues such as lagging, crashing, or incomplete visualization. To mitigate this, models must be simplified, segmented, or filtered to retain only the most relevant details for on-site use. However, this process risks losing critical information if not managed carefully.

File size and data transfer speed further complicate integration. Large BIM models demand high bandwidth and powerful processing, especially when synchronized with cloud-based platforms for real-time updates. In regions with limited internet infrastructure, maintaining consistent connectivity may be difficult, hindering collaborative workflows. Interoperability issues compound these challenges. Although standards such as Industry Foundation

Classes (IFC) and Construction Operations Building Information Exchange (COBie) exist, not all AR platforms fully support them. Proprietary software ecosystems can create data silos, restricting seamless exchange and limiting collaboration across teams using different platforms.

Human factors also influence the adoption and effectiveness of AR-BIM integration. Construction workers and managers are accustomed to traditional methods such as 2D drawings, paper schedules, and manual inspections. Transitioning to AR-enhanced workflows requires significant training and a cultural shift toward digital tools. For many workers, particularly those with limited exposure to advanced technologies, the learning curve can be steep.

Adaptation challenges are further amplified by ergonomics. Wearing AR glasses or helmets for prolonged periods may cause discomfort, eye strain, or fatigue. Handheld devices, while easier to use, can interfere with manual tasks by occupying workers' hands. Ensuring ergonomic design and usability is critical for maintaining worker acceptance and productivity. In addition, resistance to change among experienced workers may slow adoption, highlighting the need for structured training programs and gradual integration strategies (Kahn *et al.*, 2021; Xue *et al.*, 2024).

The financial cost of implementing AR-BIM integration remains a significant barrier, particularly for small- and medium-sized construction firms. High-quality AR devices, such as HoloLens or Trimble XR10 helmets, require substantial upfront investment. Beyond hardware, software licenses, model optimization tools, and cloud-based collaboration platforms add to the total cost of ownership.

Moreover, implementation costs extend beyond equipment purchases. Firms must invest in training workers, adapting workflows, and developing custom applications to align AR-BIM systems with project requirements. Ongoing maintenance, software updates, and potential device replacement further increase long-term expenses. While larger firms may absorb these costs due to the scale of their projects, smaller organizations often struggle to justify the return on investment, particularly in markets where margins are thin and project budgets are constrained.

Despite its promise, AR-BIM integration faces multiple challenges that must be addressed before it can achieve widespread adoption in construction. Technical limitations such as hardware constraints, tracking errors, and sensitivity to environmental conditions reduce reliability in the field. Data challenges, including model complexity, large file sizes, and interoperability issues, hinder seamless use of BIM information in AR environments. Human factors—ranging from the need for extensive training to ergonomic concerns and resistance to change—further complicate adoption. Finally, high costs associated with hardware, software, and implementation present economic barriers, especially for smaller firms.

Overcoming these limitations requires continuous advances in AR hardware, improved algorithms for tracking and rendering, stronger interoperability standards, and the development of cost-effective deployment strategies. With ongoing technological progress and increasing industry demand for digital tools, many of these challenges are expected to diminish over time. Nevertheless, acknowledging and addressing these limitations today is critical for unlocking the full potential of AR-BIM integration in tomorrow's construction workflows.

2.6 Future Directions

The convergence of Augmented Reality (AR) and Building Information Modeling (BIM) has already demonstrated transformative potential for construction coordination, but the trajectory of technological innovation suggests even more profound changes in the years ahead. As the construction industry advances toward digital maturity, the integration of AR-BIM systems with artificial intelligence (AI), Internet of Things (IoT) sensors, and digital twins will significantly reshape how projects are designed, executed, and managed (Monla *et al.*, 2023; Naji *et al.*, 2024). Parallel improvements in wearable AR devices promise to make these systems more practical and intuitive for daily use on construction sites. Collectively, these developments indicate a shift from isolated AR applications toward fully integrated, intelligent, and adaptive construction ecosystems.

One of the most promising directions for AR-BIM integration lies in coupling these technologies with artificial intelligence. Current AR-BIM applications are largely descriptive, allowing users to visualize project data in context. However, the addition of AI introduces predictive and prescriptive capabilities. For instance, AI algorithms trained on historical construction data can identify patterns in scheduling delays, safety risks, or cost overruns. When combined with AR, these insights can be projected directly onto the construction site, providing workers and managers with real-time, data-driven recommendations.

AI can also enhance quality control by detecting discrepancies between as-built conditions and BIM models through computer vision. Workers equipped with AR glasses could receive alerts highlighting deviations in structural placement, alignment errors, or potential clashes before they escalate into costly problems. Furthermore, AI-driven predictive analytics can support proactive maintenance by forecasting equipment failures or material degradation, ensuring long-term sustainability of constructed assets.

The integration of AR and IoT offers another compelling avenue for advancing construction coordination. IoT-enabled sensors embedded throughout construction sites can continuously monitor parameters such as temperature, humidity, vibration, or equipment performance. When connected to BIM databases, these real-time streams of information can be visualized through AR interfaces, providing workers with immediate access to critical data.

For example, IoT sensors can track the curing process of concrete, and AR devices could overlay curing status on the physical structure to inform decision-making. Similarly, wearable IoT sensors attached to workers can monitor health and safety metrics, with AR systems visualizing hazard zones, restricted access areas, or proximity warnings in real time. The fusion of AR, IoT, and BIM thus supports a responsive, data-rich environment that enhances situational awareness, operational efficiency, and safety compliance on construction sites.

The evolution toward digital twins represents a holistic vision for the future of AR-BIM integration. A digital twin is a dynamic, real-time digital representation of a physical asset that evolves throughout its lifecycle. By combining BIM as the data foundation, IoT for live monitoring, and AR as the visualization interface, digital twins can enable immersive lifecycle management of construction projects.

In practice, AR-enabled digital twins would allow stakeholders to walk through construction sites while interacting with a continuously updated model that reflects real-world conditions. This integration supports not only construction coordination but also post-construction facility management. Building owners and operators could use AR interfaces to visualize hidden systems such as HVAC, plumbing, or electrical networks for maintenance and repair (Zarzycki, 2023; Mohammadi *et al.*, 2024). Additionally, predictive maintenance powered by AI could be integrated into digital twins, ensuring that buildings remain safe, energy-efficient, and cost-effective throughout their lifecycle. The creation of fully functional digital twin ecosystems will require stronger interoperability standards and robust cloud infrastructures. However, once realized, these ecosystems promise to connect design, construction, and operation in a seamless digital thread, revolutionizing how the built environment is conceived and managed.

The practicality of AR-BIM integration depends heavily on the usability of AR devices. Current limitations related to ergonomics, battery life, and field of view are gradually being addressed by advances in wearable AR technology. Future generations of AR glasses and helmets are expected to be lighter, more comfortable, and capable of delivering high-resolution overlays with minimal latency.

Hands-free operation will be particularly valuable for construction environments where workers need to handle tools and materials. For example, AR helmets integrated with voice commands, gesture recognition, and eye-tracking will allow workers to access BIM data, receive step-by-step installation instructions, or consult remote experts without interrupting their tasks. Enhanced durability and safety compliance in AR devices will further ensure suitability for rugged construction environments.

Moreover, 5G connectivity will play a critical role in advancing wearable AR devices by enabling faster data transfer and more reliable cloud synchronization. This will

allow for real-time collaboration between on-site workers and remote stakeholders, extending the benefits of AR-BIM integration beyond the boundaries of individual project locations.

The future of AR-BIM integration in construction lies in deepening its connections with complementary digital technologies. AI will bring predictive intelligence to AR-BIM systems, transforming them from visualization tools into proactive decision-support platforms. IoT integration will embed real-time monitoring into everyday workflows, while digital twin ecosystems will enable holistic lifecycle management of assets. Simultaneously, advancements in wearable AR devices will improve usability, comfort, and accessibility, making AR-BIM tools more practical for widespread use in the construction industry.

Together, these advancements signal a paradigm shift toward a fully interconnected and intelligent construction ecosystem, where digital and physical realities are seamlessly integrated. As these technologies mature, AR-BIM integration will not only optimize construction processes but also redefine the broader built environment, aligning with the industry's goals of efficiency, safety, sustainability, and resilience (Chi *et al.*, 2022; Alvur *et al.*, 2024).

CONCLUSION

The integration of Augmented Reality (AR) with Building Information Modeling (BIM) represents a transformative advancement in the construction industry, offering a paradigm shift in how projects are designed, executed, and managed. By superimposing BIM's data-rich digital models onto the physical construction site, AR bridges the traditional gap between planning and execution, enabling stakeholders to visualize, verify, and interact with complex designs in real time. This capability fundamentally enhances the accuracy of construction activities, allowing discrepancies between as-designed and as-built conditions to be detected and resolved promptly, thereby minimizing costly errors and reducing rework.

Beyond improving accuracy, AR-BIM integration significantly enhances collaboration among project teams. Architects, engineers, contractors, and managers can access consistent, context-aware information, whether on-site or remotely. The immersive visualization offered by AR facilitates clearer communication and shared understanding, supporting faster decision-making and more effective coordination. Workers can follow step-by-step guidance directly within their environment, aligning installation tasks with millimeter-level precision, which further accelerates construction processes and improves efficiency.

The benefits of AR-BIM integration also extend to safety and resource management. Real-time visualization of hazard zones, workflow sequences, and progress monitoring helps reduce accidents, optimize labor allocation, and streamline project schedules. Cost savings are realized through lower

rates of rework, improved productivity, and more efficient use of materials.

As AR technologies continue to mature and BIM standardization advances, adoption is expected to increase across the construction industry. Enhanced device ergonomics, higher tracking accuracy, and cloud-based collaboration platforms will make AR-BIM systems more practical and accessible, even for complex, large-scale projects. Collectively, these developments position AR with BIM integration not merely as a supplementary tool, but as a core component of modern, data-driven construction workflows. Its ongoing evolution promises to redefine industry standards, promoting greater efficiency, safety, and collaboration across all phases of the built environment.

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