BIM–AR INTEGRATION IN PRACTICE: OPPORTUNITIES, CHALLENGES, AND TRADE-OFFS FROM A LIVE CONSTRUCTION CASE STUDY

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Abstract

Building Information Modelling (BIM) and Augmented Reality (AR) integration has been widely proposed to improve construction coordination, yet evidence from live site deployments remains limited. This paper presents a qualitative case study of BIM–AR use with Gamma AR on an active university accommodation project in the UK. Site observations and interviews were used to examine workflow integration, benefits, and challenges. The findings indicate that BIM–AR enhances visualisation, coordination, and early error detection when applied selectively, but is constrained by alignment reliability, site conditions, and adoption factors. The study contributes practical deployment insights for BIM–AR implementation in construction.

Introduction

The Architecture, Engineering and Construction (AEC) industry continues to face persistent inefficiencies arising from fragmented information flows, bespoke project delivery practices, and limited integration between design intent and site execution (Wuni et al., 2024; Mujahed et al., 2025; Farea et al., 2026). Building Information Modelling (BIM) has emerged as a central response to these challenges by enabling shared digital representations of built assets and supporting coordination across disciplines and project lifecycle stages (Waqar et al., 2023; Rezgui et al., 2025). Through standardised data structures and interoperable formats such as Industry Foundation Classes (IFC), BIM provides a common information backbone that improves data consistency and cross-disciplinary communication (Gerbino et al., 2021; Lee et al., 2021; Chatsuwan et al., 2025).

In parallel, Augmented Reality (AR) has gained increasing attention as a means of improving how digital construction information is accessed and interpreted on site. By overlaying virtual content onto the physical environment via mobile or head-mounted devices, AR enables more intuitive, spatially contextualised interaction with BIM data compared to conventional screen-based tools (Alizadehsalehi et al., 2020; Sidani et al., 2021; Chen and Xue, 2022). Prior research reports that AR can enhance spatial understanding, support design review and progress monitoring, and facilitate early detection of discrepancies between planned and as-built conditions (Amin et al., 2023; Girgin et al., 2023; Tan et al., 2024; Pan and Isnaeni, 2024). AR-based visualisation has also been associated with improved task accuracy and reduced error rates through just-in-time guidance and in-situ verification (Dallasega et al., 2023; Marino et al., 2024; Chaudhari et al., 2025).

The integration of BIM and AR therefore holds promise for narrowing the long-recognised gap between digital project models and physical site realities. Empirical and review studies have demonstrated potential productivity and accuracy gains from BIM–AR integration across activities such as design review, assembly, discrepancy checking, and hazard identification (Fazel and Adel, 2024; Tan et al., 2024; Arvikar et al., 2025). However, despite these reported benefits, adoption of BIM–AR on live construction projects remains limited. Prior work consistently highlights challenges related to model preparation and interoperability, alignment and tracking accuracy, hardware constraints, environmental interference, and the need for user training and workflow adaptation (Schiavi et al., 2022; Kolaei et al., 2022; Amin et al., 2023; Jin et al., 2026). Importantly, these challenges are increasingly recognised as socio-technical in nature, with organisational readiness, staff capability, and compatibility with existing information management practices playing a decisive role in determining whether AR solutions deliver value in practice (El Asmar et al., 2021; Wang et al., 2024).

A key limitation in the current body of knowledge is the scarcity of detailed, in-situ evidence documenting how BIM–AR integration is deployed on active construction sites using commercial platforms, and how such deployments interact with established project workflows. Much of the existing literature focuses on prototype systems, controlled experiments, or performance metrics such as alignment accuracy, offering limited insight into real-world deployment conditions, calibration practices, issue-management integration, and day-to-day usability trade-offs faced by site teams (Cheng et al., 2020; Girgin et al., 2023; Bhatarai et al., 2025). This gap constrains both practitioner decision-making and the translation of research outcomes into scalable industry practice.

This paper addresses this gap through a qualitative case study of BIM–AR integration using Gamma AR, a commercial AR platform deployed on a major construction project in Oxford, UK. The study examines how Gamma AR was configured to access BIM models hosted on Autodesk Construction Cloud (BIM 360), how AR visualisation was used on site via handheld devices, and how issues identified in AR were linked back to established digital coordination workflows. Drawing on site observations and semi-structured interviews with project staff, the research investigates both the opportunities created by BIM–AR integration, such as enhanced visualisation, improved coordination, and early error detection, and the challenges encountered during live deployment, including alignment reliability, environmental and hardware limitations, data-update frictions, and user adoption barriers. Some of these barriers, particularly around usability, trust, and model interaction, can also be interpreted through the lens of Human–Data Interaction (HDI), where constraints in *legibility*, *agency*, and *negotiability* (Mortier et al., 2014) may help explain the limited mainstream adoption of BIM–AR technologies in construction settings.

The contribution of this paper is threefold. First, it provides an empirically grounded account of an end-to-end BIM–AR deployment using a commercial toolchain under live construction conditions. Second, it synthesises practitioner experiences into a structured analysis of observed benefits and challenges, complementing prototype-focused research with deployment-level evidence. Third, it derives practical implications for both construction teams considering AR adoption and developers seeking to reduce friction in BIM–AR integration, particularly in relation to workflow fit, usability, and calibration robustness.

The remainder of the paper is structured as follows: the next section presents the research methodology and case study context; this is followed by results and discussion; and the paper concludes with key findings and implications for future research and practice.

Methodology

This research adopted a qualitative case study approach to investigate the deployment of a BIM-integrated Augmented Reality (AR) solution on an active construction site. A case study method was selected as it is well suited to investigating emerging digital technologies in real-world contexts, where implementation conditions, workflows, and user interactions cannot be meaningfully isolated or controlled. Rather than seeking to quantify performance metrics, the study focuses on understanding how BIM–AR integration is configured, used, and experienced in practice.

Case Study Context

The case study was conducted on the Clive Booth Student Village redevelopment project at Oxford Brookes University, UK; a large-scale student accommodation development delivered by a major UK contractor. The project employed a coordinated BIM model hosted on Autodesk Construction Cloud (BIM 360) to support design coordination and construction management. Gamma AR, a commercial AR application designed for construction use, was introduced on the project to enable on-site visualisation of BIM models and support spatially contextualised issue identification.

Gamma AR was used via handheld tablet devices to overlay BIM content onto the physical construction environment in real time as shown in Figure 1. The application was configured to access the latest project models from BIM 360 and to synchronise AR-based issues capture back into the project's established digital coordination workflows. The deployment therefore represented a realistic, industry-facing implementation rather than a prototype or experimental system.

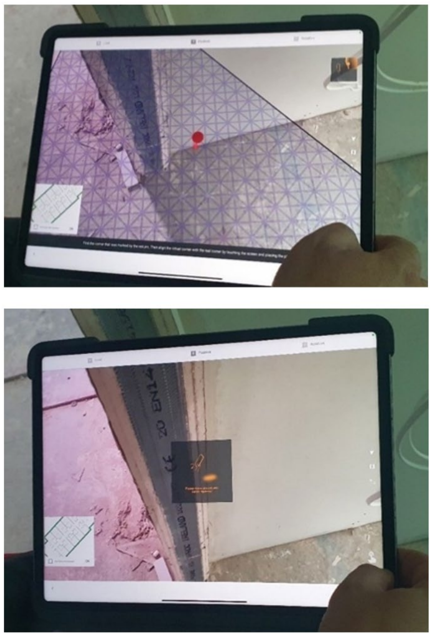

Figure 1: Identifying the purple mesh on a flat surface before restarting the Gamma Application

BIM-AR Workflow Configuration

To enable AR visualisation, the project's BIM model authored in Autodesk Revit, was exported in formats compatible with Gamma AR (including RVT, IFC, and NWC) and made available through the cloud-based BIM collaboration platform. On site, users selected relevant floors or zones within the Gamma AR application and aligned the virtual model to the physical environment using identifiable reference features such as structural gridlines and slab edges. Once aligned, the application maintained model registration using marker-less tracking based on the tablet's onboard sensors and camera.

A key aspect of the workflow was the integration of AR-based issue identification with the project's existing issue management processes. Discrepancies observed through the AR overlay could be logged directly within Gamma AR, including descriptive text and images, and synchronised back to BIM 360. This enabled issue identified in the field to be reviewed and addressed by the wider project team using familiar coordination tools. Figure 2 illustrates this BIM–AR workflow, from BIM

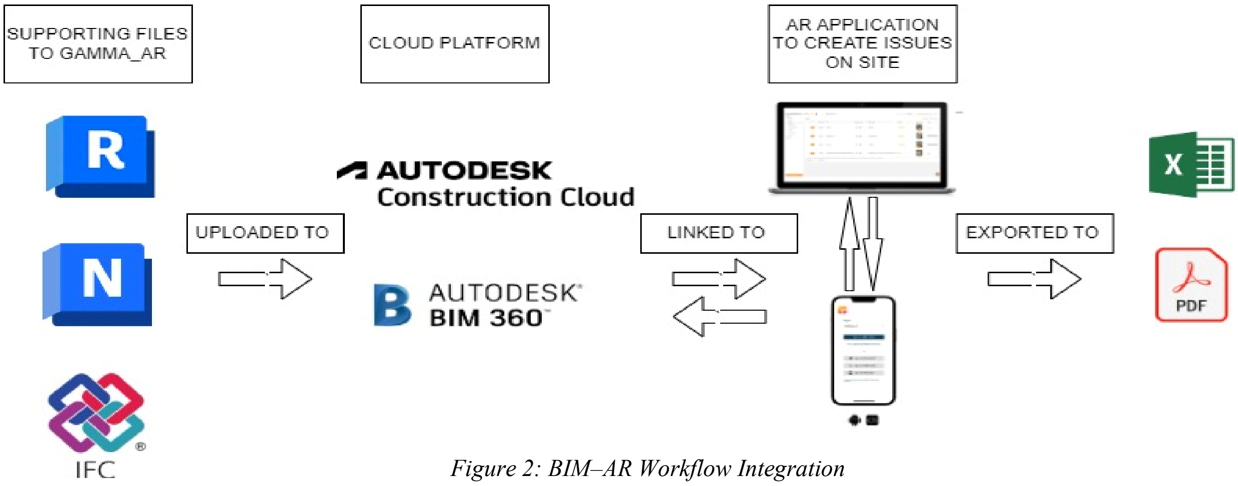

Figure 2: BIM–AR Workflow Integration

authoring and cloud-based model management to on-site AR visualisation and issue synchronisation.

Data Collection

Data collection combined direct site observations with semi-structured interviews involving members of the project team who actively used Gamma AR. Multiple site visits were conducted during which the researcher observed how site engineers and managers used the AR application for tasks such as installation verification, coordination discussions, and progress checks. Observational notes focused on alignment procedures, usage patterns, perceived benefits, and practical difficulties encountered during use.

Semi-structured interviews were conducted with six construction professionals involved in the project, including the site manager, BIM coordinator, a digital construction advisor, and site engineers. Participants were selected based on direct involvement with the Gamma AR deployment and their varied roles in on-site decision-making and BIM coordination. Interview questions explored participants' experiences with the AR tool, perceived value for construction coordination, challenges related to accuracy, usability, and workflow integration, and views on adoption and training requirements. A short questionnaire with 10 site-based staff members who had trialed the AR tool was used to supplement interview data and capture recurring themes across participants.

Data Analysis

The collected qualitative data were analysed using a thematic approach. Observation notes and interview transcripts were coded to identify recurring patterns related to (i) opportunities created by BIM–AR integration, such as enhanced visualisation, coordination, and error detection, and (ii) challenges encountered during deployment, including technical limitations, environmental constraints, and user adoption issues. The analysis focused on identifying practical trade-offs and deployment considerations rather than measuring system performance quantitatively. The overall data collection and analysis process adopted in this study is summarised in Figure 3.

Figure 3: Data collection and thematic analysis process adopted in the Gamma AR case study

Scope and Limitations

The study is based on a single case study and is not intended to provide statistically generalisable results. Instead, it offers empirically grounded insights into BIM–AR deployment under real construction conditions. The findings should therefore be interpreted as illustrative of practical opportunities and challenges, rather than definitive performance evaluations of AR technology.

Results and Discussion

The deployment of Gamma AR on the Clive Booth Student Village project provided insight into how BIM–AR integration functions under real construction conditions. The findings are organised around three themes: (i) opportunities observed during on-site use, (ii) challenges encountered during deployment, and (iii) practical trade-offs that shaped how the technology was ultimately used in practice.

Opportunities of BIM-AR Integration

The Gamma AR deployment revealed several opportunities where BIM–AR integration added value to construction coordination and decision-making. Importantly, these opportunities emerged not from automation or measurement precision, but from enhanced contextual access to BIM information within the physical site environment. One site engineer remarked, *"It's easier to understand what you're building when the model is literally on the slab. It helps reduce confusion from the drawings."* Similarly, the BIM coordinator observed, *"Having the model in the space gave the client a clearer picture — they could point out issues straight away."*

Enhanced visualisation of design intent in context

The most consistently reported opportunity was improved spatial understanding of design intent on site. By overlaying BIM models directly onto partially constructed spaces, Gamma AR enabled site personnel to visualise upcoming works in context, particularly during early fit-out stages where two-dimensional drawings were difficult to interpret. AR was frequently used to preview partition layouts, service routes, and spatial clearances prior to installation, supporting more intuitive comprehension of scope and sequence. From a Human–Data Interaction (HDI) perspective, this enhanced the *legibility* of BIM data by making abstract digital information more comprehensible in its physical context, particularly for those without prior technical training.

This finding aligns with prior research showing that AR enhances spatial cognition and design comprehension by reducing the mental effort required to translate abstract representations into physical form (Sidani et al., 2021; Chen and Xue, 2022). However, the case study suggests that these benefits are most pronounced when AR is used selectively for spatially complex tasks, rather than as a general-purpose visualisation tool. In this sense, AR acted as a cognitive aid, supporting shared understanding rather than replacing conventional drawings.

Improved coordination and communication workflows

BIM–AR integration supported stronger on-site coordination by enabling discrepancies between the BIM model and site conditions to be identified and discussed directly within the physical environment. In several observed instances, AR overlays revealed potential clashes, such as conflicts between services and structural elements that had not been immediately apparent in drawings or model reviews conducted off-site.

The ability to capture issues directly from the AR interface and synchronise them with BIM 360 shortened feedback loops between site and design teams, reducing reliance on post-hoc interpretation of photographs or annotated drawings. This supports findings from prior studies reporting that BIM–AR integration can improve coordination efficiency by anchoring discussions around a shared, spatially contextualised representation (Garbett et al., 2021; Girgin et al., 2023). Notably, the effectiveness of this workflow depended on tight integration with existing issue-management processes; AR added value by augmenting, rather than bypassing, established coordination practices.

Error reduction and quality assurance support

AR functioned as a practical quality assurance aid by enabling rapid "overlay checks" between planned and installed elements. In one example, a minor misalignment in pipework was detected when the virtual model did not align with the physical installation, prompting immediate correction. While AR was not treated as a precision measurement tool, it provided a fast and visually intuitive means of identifying potential issues early, reducing the likelihood of downstream rework.

This use of AR as a screening mechanism rather than a substitute for formal inspection or surveying was viewed positively by site staff and is consistent with prior experimental findings that AR can reduce human error in construction tasks by improving perceptual alignment between design intent and execution (Fazel and Adel, 2024; Surri and Kuncoro, 2025). The case study reinforces that AR's value in quality assurance lies in early detection and visual confirmation, rather than in guaranteeing geometric accuracy.

Time savings in issue identification and resolution

Although time savings were not formally quantified, interviewees consistently reported that AR-based issue identification reduced time spent interpreting drawings and clarifying spatial problems. The integration of issue capture within the AR environment allowed problems to be communicated with fewer clarification cycles, particularly for spatially complex issues.

Site managers estimated that certain issues were resolved in approximately half the time compared to conventional workflows, largely due to improved shared understanding rather than process automation. This aligns with findings by Wang et al. (2024), who reported that AR-supported workflows reduced selected process durations by up to 50% in comparable construction contexts. However, the case study suggests that such time savings are highly task-dependent and should be interpreted as indicative rather than guaranteed performance gains.

Stakeholder engagement and confidence

An indirect but notable opportunity was improved engagement with clients and non-technical stakeholders. During site visits, AR visualisations helped communicate layouts, progress, and design intent more effectively than drawings or screen-based models, increasing stakeholder confidence in coordination decisions. This immersive mode of communication reduced misunderstandings and supported more informed discussions around design changes.

While difficult to quantify, these effects echo prior research suggesting that AR's experiential "walkthrough" capability can enhance stakeholder engagement and support transparency in construction projects (Mutis and Ambekar, 2020; Wang et al., 2013). In the present case, AR also contributed to a perception of innovation among site staff, supporting openness to digital tools. However, such engagement benefits were contingent on usability and reliability; technical friction quickly diminished perceived value.

Challenges in BIM-AR Deployment

While the Gamma AR trial demonstrated clear value, it also revealed a range of challenges that reflect the current limitations of BIM–AR integration under live construction conditions. These challenges are discussed below, drawing on both empirical observations from the case study and findings reported in recent literature.

Model alignment and registration reliability

Achieving and maintaining reliable alignment between the BIM model and the physical environment was one of the most persistent technical challenges as shown in Figure 4. Users reported occasional drift or offset in the AR overlay, typically attributable to imprecise initial calibration, cumulative tracking error, or changes in the surrounding environment. Similar alignment instability has been widely reported in prior studies, particularly in markerless AR systems deployed on construction sites (Surri and Kuncoro, 2025; Schiavi et al., 2022).

To mitigate this issue, site staff relied on known reference features (e.g., slab edges, gridlines) and periodically rechecked alignment during use. While these workarounds were effective in maintaining acceptable visual correspondence, they introduced additional setup effort and reduced confidence in using AR for fine-grained verification tasks. Minor alignment errors also risked false interpretations, such as suggesting an installation was incorrect when the overlay itself was inaccurate, highlighting the need for more robust and transparent registration mechanisms. This reinforces findings by Cheng et al. (2020) and Girgin et al. (2023), who emphasis that registration reliability remains a critical barrier to dependable AR deployment in construction.

Figure 4: Aligning the level manually

Environmental and site condition constraints

Construction site conditions introduced several practical limitations for AR use. Bright daylight caused screen glare that reduced visibility on tablet displays, while cluttered or visually homogeneous environments occasionally disrupted feature detection and tracking stability. Unlike controlled indoor settings, lighting and surface conditions on site cannot be regulated, constraining when and where AR can be used reliably.

These challenges align with previous research noting that environmental variability significantly affects AR performance in construction contexts (Machado and Vilela, 2020; Kolaei et al., 2022). In practice, AR use was often restricted to shaded areas, interior spaces, or specific times of day to ensure acceptable visibility. This highlights the importance of hardware and visualisation modes optimised for outdoor use, as well as tracking algorithms resilient to changing lighting and surface conditions.

Hardware and usability limitations

The choice of hardware strongly shaped the AR experience. Using tablets provided accessibility and a low barrier to entry, consistent with industry preferences for familiar devices. However, prolonged use resulted in rapid battery drain and user fatigue from holding the device for extended periods. While head-mounted displays were discussed, they were considered impractical for routine site work due to known limitations such as restricted field of view, added weight, and user discomfort.

These observations are consistent with recent studies reporting that extended AR use, particularly with head-mounted devices, can cause physical discomfort and reduced situational awareness, potentially increasing safety risks on construction sites (Chen et al., 2024; Sidani et al., 2021). Although Gamma AR's compatibility with standard mobile devices is a strength, effective deployment still depends on access to relatively recent hardware with sufficient processing power and battery capacity, which introduces procurement and cost considerations.

Data management and integration frictions

Maintaining smooth BIM–AR data flow presented additional challenges. Large or highly detailed BIM models required simplification to ensure acceptable performance on mobile devices, necessitating deliberate model optimisation strategies. Furthermore, model updates introduced workflow friction: exporting and reloading revised models into Gamma AR took time and depended on reliable site connectivity.

On one occasion, limited Wi-Fi connectivity delayed synchronisation of newly logged issues with BIM 360, echoing findings from prior studies that highlight connectivity and data transfer as persistent constraints for BIM-based AR in construction environments (Cheng et al., 2020; Bhatarai et al., 2025). While Gamma AR's integration with BIM 360 was broadly effective, not all metadata were consistently accessible through the AR interface, limiting the depth of information available in the field. These findings underscore the dependence of BIM–AR workflows on robust digital infrastructure and carefully planned update strategies, including offline or pre-download options where network coverage is unreliable.

User adoption and learning curve

Beyond technical constraints, human factors emerged as a significant barrier to adoption. User acceptance varied across roles and experience levels, with initial scepticism particularly evident among staff accustomed to traditional drawings and paper-based workflows. Survey and interview feedback highlighted limited awareness of AR capabilities, resistance to changing established practices, and concerns about implementation cost and learning effort.

Adoption improved when the technology was actively championed by site leadership and supported by hands-on demonstrations and vendor assistance. However, participants consistently noted that effective use "takes time to learn," reinforcing findings from Wang et al. (2024) and El Asmar et al. (2021) that training, managerial commitment, and usability strongly shape AR uptake in construction. These observations indicate that ease of use, intuitive interfaces, and minimal interaction overhead are critical for sustaining long-term adoption on site.

Table 1 summarises the key opportunities and challenges observed during the Gamma AR deployment, providing an overview of the empirical findings discussed in this section.

Table 1: Summary of key opportunities and challenges observed during the Gamma AR case study.

Opportunities (Benefits Observed)	Challenges (Issues Encountered)
Enhanced visualisation of design intent in real spatial context, improving comprehension of complex layouts.	Alignment and registration issues - occasional model drift requiring manual recalibration and confidence checks
Improved coordination and communication through shared AR views and faster on-site issues identification	Lighting and environment interference - screen glare and tracking instability under bright or cluttered site conditions.
Error reduction and quality assurance support by identifying discrepancies early and reducing downstream rework	Hardware limitations - battery drain, device fatigue, and dependence on relatively recent mobile hardware
Time savings in issue verification and resolution through streamlined AR-based logging and visual explanation	Data integration frictions - model preparation effort, update delays, and reliance on reliable site connectivity
Stakeholder engagement via intuitive 3D visualisation that improved confidence during site discussions	User adoption barriers - learning curve, resistance to change, and need for training and managerial support

Trade-offs and Practical Implications

The Gamma AR case study highlights several trade-offs inherent in BIM–AR deployment on live construction projects. While AR improved visualisation, coordination, and issue communication, these benefits were accompanied by additional effort related to model preparation, alignment, device management, and user training. Understanding these trade-offs is critical for determining when and how AR should be deployed to deliver net value in practice.

A central trade-off observed was productivity versus preparation. AR supported faster inspections, coordination discussions, and issue resolution once operational; however, achieving this reliability required upfront investment in model optimisation, calibration, and troubleshooting. For brief or low-complexity tasks, this overhead could outweigh the immediate benefits. In contrast, for projects characterised by spatial complexity and repeated coordination demands, the investment was more likely to pay off. A practical implication is that AR should be targeted at high-value use cases, such as scheduled coordination walks, stakeholder reviews, or verification of critical installations rather than applied indiscriminately across all site activities.

A second trade-off concerned immersion versus practicality. Although head-mounted AR systems can offer hands-free and immersive experiences, the project team preferred tablet-based AR due to comfort, familiarity, and ease of integration into everyday site routines. This suggests that the most effective AR solutions for construction are not necessarily the most immersive, but those that fit seamlessly into existing workflows. From a design perspective, construction-oriented AR tools should prioritise usability, rapid set-up, outdoor-readable displays, and one-handed operation over advanced visual realism.

The study also revealed a trade-off between accuracy and effort. High-precision alignment typically demands additional setup steps, such as multiple calibration points or physical markers, whereas faster registration can reduce confidence in positional accuracy. In this case, AR was used pragmatically as a screening and communication tool, with apparent discrepancies verified using conventional methods such as laser measurement. This approach helped maintain trust in technology while avoiding over-reliance. Design implications include the need for clearer uncertainty cues, faster recalibration mechanisms, and training that reinforces AR as a decision-support aid rather than an infallible measurement system. From a Human–Data Interaction (HDI) perspective, Gamma AR supported *agency* by enabling users to interrogate and act on real-time overlays. *Negotiability* was evident in on-site discussions where planned elements were confirmed or challenged in context. However, these affordances also raised *privacy* concerns around the passive capture of site conditions and worker activity, pointing to the need for ethical data handling and user awareness.

From an organisational perspective, the trade-off between innovation and disruption was evident. Introducing AR altered established routines for issue reporting and coordination, requiring staff to adapt to new information flows. Adoption improved when AR use was visibly supported by site leadership and introduced incrementally with clear purpose. This reinforces prior findings that managerial commitment, training, and structured protocols are decisive factors in successful AR deployment in construction (Wang et al., 2024). Without attention to these human factors, even technically robust AR solutions risk limited uptake.

Several broader design implications emerge from the case. First, tight integration with existing common data environments is essential; AR tools should operate as extensions of established platforms rather than standalone systems. Second, interface simplicity and low interaction overhead are critical, as on-site users have limited tolerance for complex configuration. Third, future AR platforms could further extend value through real-time collaboration features, such as multi-user sessions or remote expert support, which were not available in this deployment but were strongly desired by participants.

Overall, the findings point to a pragmatic principle for BIM–AR deployment: flexibility over prescription. Gamma AR was most effective when treated as an optional support tool rather than a mandated process. Site teams used AR when it added clear value and reverted to conventional methods when these were faster or more reliable. This coexistence suggests that AR does not need to replace established practices to be useful; instead, it can enhance them when deployed selectively and thoughtfully.

Conclusion

This paper investigated the deployment of a BIM-integrated Augmented Reality (AR) solution on an active construction site through a qualitative case study of Gamma AR on a large-scale university accommodation project in the UK. By focusing on real-world use rather than controlled experimentation, the study provides empirical insight into how BIM–AR integration operates in practice and interacts with established construction workflows.

The findings demonstrate that BIM–AR integration can deliver tangible benefits when applied selectively to coordination, visualisation, and quality assurance tasks. AR-supported overlays improved spatial understanding of design intent, facilitated clearer communication between site and office teams, and enabled earlier identification of discrepancies between planned and as-built conditions. These benefits were driven not by automation or precision measurement, but by enhanced shared understanding and contextualised access to BIM information. When integrated with existing issue-management workflows, AR reduced interpretation effort and shortened feedback loops.

At the same time, the study highlights practical constraints on BIM–AR deployment, including alignment reliability, environmental conditions, hardware limitations, model maintenance effort, and user adoption factors. The findings indicate that AR is most effective when treated as a complementary tool rather than a replacement for established practices, supporting early detection and discussion while relying on conventional methods for precise verification.

The contribution of this paper lies in documenting an end-to-end BIM–AR deployment using a commercial platform under live construction conditions and articulating the trade-offs that shape practical use. While limited to a single case study and handheld AR configuration, the findings provide deployment-level evidence that can inform both practitioners considering AR adoption and developers seeking to improve BIM–AR integration. Overall, the study reinforces that realising the potential of BIM–AR depends less on technological sophistication than on alignment with site realities, user practices, and existing digital workflows.

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