International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(REVIEW ARTICLE)

Check for updates

Augmented virtual reality in South African education and the field of architectural engineering for global impact

Hyacinthe Tonga *

Department of Architectural Technology and Interior Design, Faculty of Engineering, the Built Environment and Technology, Nelson Mandela University, 6001, University Way, Summerstrand, Gqeberha.

International Journal of Science and Research Archive, 2025, 15(03), 1510-1523

Publication history: Received on 16 May 2025; revised on 23 June 2025; accepted on 25 June 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.3.1941

Abstract

This paper investigates the integration of Augmented Virtual Reality (AVR) technologies within South African higher education, with a concentrated emphasis on their application in architectural engineering. As immersive learning tools continue to reshape global pedagogical landscapes, AVR emerges as a particularly promising medium for enhancing spatial cognition, deepening student engagement, and aligning graduates with the evolving demands of the global built environment industry. The study foregrounds the case of Nelson Mandela University (NMU), a pioneering South African institution that has demonstrated leadership in this domain through the implementation of the Virtual Architecture Teaching Programme (VATP). Through this initiative, NMU has successfully embedded immersive technologies into design studios and interdisciplinary learning environments, offering critical insights into curriculum innovation, digital equity, and industry-aligned pedagogy. Drawing on both literature and emerging practice, the paper outlines the pedagogical benefits of AVR, assesses institutional and systemic challenges including infrastructure costs, curriculum integration, and staff capacity and synthesizes best practices for sustainable adoption. The findings contribute to a growing body of knowledge on immersive education in the Global South and culminate in a set of strategic recommendations aimed at expanding AVR integration in architecture and engineering programmes across Africa and beyond.

Keywords: Augmented Virtual Reality (AVR); Immersive technologies; Immersive education; Virtual Architecture Teaching Programme (VATP)

1. Introduction

The Fourth Industrial Revolution has ushered in a new era in education and professional training, marked by the increasing adoption of immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR). These technologies, when combined as Augmented Virtual Reality (AVR), offer transformative possibilities for learning, particularly in disciplines that rely heavily on spatial reasoning, creative visualization, and technical precision such as architectural engineering [5]. AVR allows for the simulation of real-world environments and the superimposition of digital content onto physical spaces, thereby enabling learners to engage more deeply with complex systems and design challenges [3].

Globally, institutions are exploring the potential of AVR to enhance learning outcomes, promote active and experiential learning, and prepare students for digitalized professional environments. In this global shift, South Africa is emerging as a strategic site of innovation, where universities are beginning to adopt AVR tools not only to enrich teaching and learning but also to address systemic educational inequalities [2]. The integration of AVR is especially promising for South Africa's architectural engineering sector, which faces the dual challenge of maintaining international competitiveness while responding to local infrastructural, environmental, and social imperatives.

* Corresponding author: Hyacinthe Tonga

One institution at the forefront of this transformation is Nelson Mandela University (NMU). Located in Gqeberha in the Eastern Cape, NMU has demonstrated a clear commitment to digital innovation in education, particularly within its Faculty of Engineering, the Built Environment and Technology (EBET). Through initiatives like the Virtual Architecture Teaching Programme (VATP), NMU has begun to systematically integrate AVR into the architectural design curriculum [4]. The programme provides students with access to VR walk-throughs, AR model overlays, and collaborative digital workspaces, enabling a reimagining of traditional studio-based pedagogy in line with contemporary technological trends.

This paper therefore seeks to investigate the role and potential of AVR in South African architectural engineering education, with a specific focus on NMU as a pioneering case. The study critically explores how AVR can enhance educational delivery, improve student learning experiences, foster industry alignment, and potentially position South Africa as a contributor to global innovations in immersive education. While highlighting successes, the paper also addresses the practical challenges of implementation including issues of cost, accessibility, infrastructure, and academic training and proposes a framework for broader adoption across similarly positioned institutions in the Global South.

As higher education increasingly moves toward hybrid, digital-first models, South Africa's efforts to adopt AVR technologies will play a key role in determining its ability to educate a new generation of architects and engineers who are not only technically proficient but also globally competitive and locally responsive. The findings of this study aim to contribute to the broader discourse on digital transformation in education, with implications for policy, practice, and further research in immersive learning environments.

2. Augmented Virtual Reality in South African Education

2.1. Understanding Augmented Virtual Reality (AVR)

Augmented Virtual Reality (AVR) refers to the combined use of Virtual Reality (VR) and Augmented Reality (AR) to create enriched, interactive learning environments. VR immerses users in fully digital, computer-generated environments, often experienced through head-mounted displays or immersive screens. AR, on the other hand, overlays digital content such as 3D models, data, or instructions onto the physical world using devices like smartphones, tablets, or AR glasses [3]. Together, these technologies offer a powerful pedagogical approach that blends imagination with realism, facilitating experiential and spatial learning, particularly in fields like architecture, engineering, and medicine [5].

Pedagogically, AVR enables students to engage with abstract concepts in tangible ways walking through digital buildings before they are constructed, manipulating complex systems, or viewing structures from multiple perspectives. This aligns closely with constructivist learning theories, which emphasize active learning, multisensory interaction, and student-centred exploration [6].

2.2. Educational Transformation in the South African Context

In South Africa, the adoption of immersive learning technologies is still in its formative stages. Nevertheless, the country is increasingly acknowledging the role of AVR in modernising teaching and addressing spatial, social, and infrastructural challenges in higher education. This transformation is driven by both global technological trends and the need to localise innovations to suit South Africa's developmental context [2].

One of the primary motivators for AVR integration in South African education is its ability to bridge spatial and resource gaps. For institutions serving rural and under-resourced communities, AVR can offer students access to virtual labs, simulated construction sites, or digitally reconstructed heritage buildings experiences they may never encounter physically [1]. It is particularly valuable for design and engineering education, where access to building sites, fabrication labs, or large-scale physical models is often limited due to cost, location, or safety concerns.

However, the broader implementation of AVR technologies in South Africa faces several systemic challenges. These include limited access to high-speed internet, insufficient digital literacy among educators, and the high cost of VR hardware and software. The digital divide, already present in South African society, is often exacerbated by the technical demands of immersive technologies, which require robust computing infrastructure and specialised technical support [2]. As such, AVR adoption tends to be clustered in a few well-funded institutions, while others struggle to keep pace.

2.3. Institutional Adoption and National Momentum

Despite these challenges, several South African universities have taken proactive steps to explore and institutionalise AVR. These include:

- University of the Witwatersrand (Wits): Through its Digital Dome and Mining Simulation platforms, Wits has experimented with VR for geospatial learning and construction safety training.
- Stellenbosch University: The Faculty of Engineering has piloted immersive virtual design and prototyping labs for mechanical and civil engineering.
- University of Cape Town (UCT): The School of Architecture, Planning, and Geomatics has explored 3D spatial mapping and VR model integration in urban design modules.
- Nelson Mandela University (NMU): NMU stands out for its structured, cross-disciplinary integration of AVR across architectural engineering education through its Virtual Architecture Teaching Programme (VATP) [4]. The programme leverages both desktop-based VR and mobile AR applications, enabling students to visualise complex building structures, conduct virtual site visits, and present designs using immersive walk-throughs.

This emerging momentum is supported by the Council on Higher Education (CHE) and various digital transformation frameworks in South Africa's post-school education system. The Department of Higher Education and Training (DHET) has also acknowledged the need to enhance digital learning capabilities in the country's public institutions, particularly through blended and hybrid learning strategies that include immersive technologies.

2.4. Benefits Specific to South African Architectural Education

For South African architecture and engineering students, AVR supports:

- Visual-Spatial Learning: Students often struggle with abstract geometries, technical drawings, and spatial relations. AVR makes these concepts interactive and experiential [3].
- Cost-Effective Design Testing: Instead of building expensive prototypes or physical models, students can simulate and test their ideas digitally, fostering design iteration and innovation without material waste
- [5].
- Culturally Relevant Storytelling: AR tools allow for the integration of local heritage, indigenous knowledge, and vernacular architecture into design studios creating more contextually grounded learning experiences.
- Workplace Readiness: Exposure to AVR tools aligns students with industry trends, such as BIM, parametric modelling, and digital twin technologies enhancing graduate employability and positioning South Africa competitively in the global design economy [2].

2.5. NMU's Contribution to Local and Regional Capacity Building

Nelson Mandela University's pioneering efforts illustrate how targeted AVR initiatives can serve both local and regional development goals. The VATP integrates AVR into undergraduate and postgraduate architecture courses, enabling students to present their work not only on physical models but also through fully navigable VR environments. Staff training, curriculum redesign, and investment in immersive studios have made NMU a model for sustainable digital transformation [4].

Furthermore, NMU is actively exploring ways to expand access through mobile VR and low-data AR platforms, ensuring that students from township and rural areas are not excluded from immersive education due to bandwidth or hardware limitations.

AVR technologies present a compelling opportunity to enhance education across South African institutions, especially in design-heavy fields like architecture and engineering. While systemic barriers remain, institutions like NMU have demonstrated that intentional planning, inclusive curriculum integration, and strategic investment can overcome many obstacles. As more universities experiment with immersive platforms, a national dialogue on how best to fund, scale, and democratise AVR adoption is becoming increasingly urgent and necessary.

3. AVR in Architectural Engineering: The NMU Case

3.1. The Relevance of AVR to Architectural Engineering Education

Architectural engineering is a complex, interdisciplinary field that bridges structural engineering, architectural design, and environmental systems. Education in this domain requires learners to grasp abstract spatial concepts, analyze multidimensional structures, and integrate diverse technical systems all while considering real-world constraints such as material properties, environmental impact, and human behaviour. Traditional pedagogical methods often based on static drawings, physical models, and 2D representations frequently fall short in helping students fully internalize and visualize these multidimensional interactions [3].

Augmented Virtual Reality (AVR) presents a paradigm shift in architectural engineering education by enabling immersive, interactive, and highly visual learning experiences. With VR, students can explore full-scale digital environments, conduct real-time virtual site analyses, and simulate user navigation within designed spaces. AR further enhances this by allowing students to superimpose digital building elements onto physical environments, facilitating real-world contextual awareness and critical analysis [5]. These capabilities align well with the pedagogical needs of architectural engineering, offering students the tools to “experience” architecture before it is built, and to iterate designs within a low-risk, high-feedback environment.

3.2. The Emergence of AVR at Nelson Mandela University (NMU)

Nelson Mandela University (NMU) has emerged as a national leader in the educational deployment of immersive technologies within the architectural discipline. Situated in the Eastern Cape, NMU’s Faculty of Engineering, the Built Environment and Technology (EBET) has implemented a multi-pronged approach to AVR integration that combines infrastructure development, staff training, pedagogical redesign, and research [4]. Central to this initiative is the Virtual Architecture Teaching Programme (VATP) a strategic intervention that positions immersive education at the heart of architectural design learning.

The VATP has been developed in response to several converging factors: the growing digital literacy of Generation Z learners; the increasing demand for virtual design capabilities in industry; and the pedagogical shortcomings of conventional architectural education in visual-spatial reasoning [2]. Through VATP, NMU provides students with access to VR-enabled design studios, AR-supported critique environments, and cloud-based collaboration tools, all aimed at enhancing student interaction with spatial information and architectural systems.

3.3. Implementation Strategies and Tools at NMU

NMU’s AVR implementation is marked by a carefully scaffolded infrastructure that includes dedicated VR studios equipped with headsets (such as Oculus Rift and Meta Quest), high-spec computers, and design software including Revit, Rhino, Unity, and Enscape. These platforms allow students to generate and explore interactive, real-time 3D models of their projects. A core feature of the curriculum involves students conducting immersive walk-throughs of their digital buildings, where they can assess the scale, proportion, lighting, circulation, and experiential quality of architectural spaces before physical fabrication begins [4].

AR is also used for enhanced design critiques and review processes. Using mobile tablets or AR viewers, both lecturers and peers can overlay digital structures onto printed plans or physical models, enabling real-time assessment of structure, geometry, and spatial logic. This has proven particularly useful in studio-based learning environments, where iterative feedback and visual communication are central to the design process [6].

NMU has also introduced collaborative AVR spaces, where teams of students can co-design and critique projects in shared virtual environments. These multi-user VR platforms simulate real-world design charrettes, fostering interdisciplinary collaboration between architecture, civil engineering, and construction management students.

3.4. Pedagogical Impacts and Student Outcomes

Early assessments at NMU indicate that AVR-supported pedagogy is contributing to significant improvements in student understanding and engagement. Students demonstrate stronger visual-spatial awareness, better technical articulation in their design presentations, and an increased ability to self-assess and refine their projects during the design process [2]. Notably, the immersive experience of "walking through" a virtual building has been shown to deepen students’ comprehension of proportional relationships, material transitions, and light behaviour elements that are often difficult to convey through 2D drawings or static models.

Moreover, students report increased motivation and satisfaction, citing the interactivity and realism of AVR environments as key drivers of their learning engagement [3]. The ability to receive instant, visual feedback encourages a more iterative and reflective design process, moving students away from linear project development toward more experimental and collaborative learning cycles.

3.5. Research and Knowledge Production at NMU

Beyond teaching, NMU's adoption of AVR has generated significant momentum in academic research. Staff from the Faculty of EBET are currently involved in several studies investigating the pedagogical efficacy, technological barriers, and cognitive outcomes of immersive education in architectural engineering. Topics include the integration of AVR in first-year design thinking modules, comparative studies between traditional and VR-supported project outcomes, and assessments of lecturer readiness to adopt immersive technologies [4].

This research has led to the development of an open-access toolkit to support AVR adoption across other South African institutions. This includes instructional materials, software recommendations, sample VR lesson plans, and mobile-friendly AR model files intended to reduce the entry barriers for under-resourced universities.

3.6. Addressing Challenges Through Institutional Strategy

NMU's success in AVR integration has not been without challenges. Financial constraints, hardware maintenance, and inconsistent student access to home internet have posed notable obstacles. However, the university has responded by piloting hybrid AVR learning models, wherein students can access simplified VR content via mobile applications or through university-provided VR kits. Training for lecturers is ongoing, with workshops and digital learning communities being established to share best practices and troubleshoot implementation issues [5].

Crucially, NMU has grounded its AVR strategy in the principle of inclusive innovation ensuring that immersive learning tools serve not only high-performing urban students but also those from township and rural communities, thereby helping to reduce digital inequities in architectural education [1].

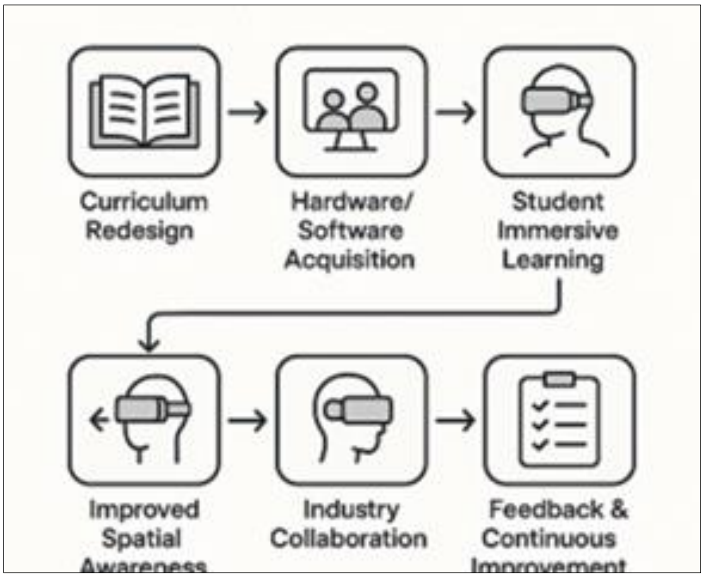

Figure 1 Flow Diagram of AVR Integration at NMU

The integration of Augmented Virtual Reality into architectural engineering education at Nelson Mandela University illustrates the power of immersive technology to enrich teaching, support design thinking, and prepare graduates for the demands of a digitally transforming industry. NMU's VATP has provided a replicable model of how AVR can be effectively and inclusively embedded in curriculum, practice, and research. As AVR continues to evolve, NMU's experience highlights the importance of strategic planning, institutional commitment, and a learner-centred approach in realising the full potential of immersive design education.

4. Benefits of Integrating AVR in NMU and Beyond

The integration of Augmented Virtual Reality (AVR) into architectural engineering education offers transformative benefits that extend beyond enhanced visualisation. At Nelson Mandela University (NMU), these benefits have become increasingly evident through the Virtual Architecture Teaching Programme (VATP), which has redefined how students engage with space, structure, and design logic. The section below outlines key benefits experienced at NMU and discusses their potential impact across South African higher education.

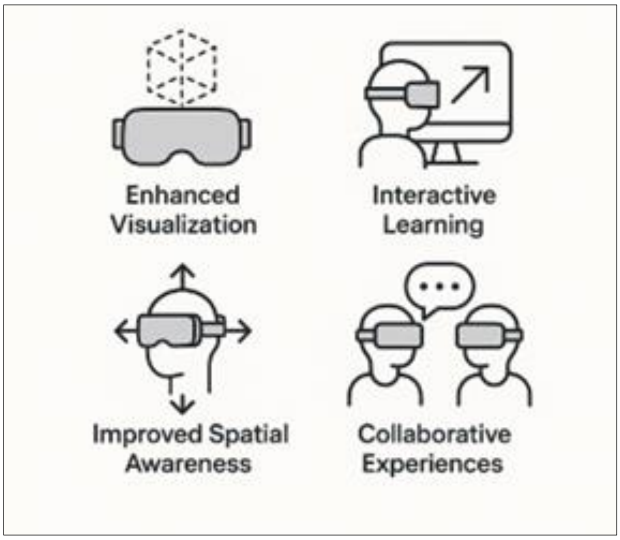

Figure 2 Educational Benefit of AVR

4.1. Enhanced Spatial and Visual Learning

One of the most immediate and measurable benefits of AVR in architectural education is its ability to strengthen visual-spatial intelligence, which is essential for understanding geometry, scale, and form. Traditional methods such as 2D drafting and scale models offer limited insight into how people will interact with designed environments. AVR bridges this gap by enabling students to "walk through" their designs in life-size proportions, offering perspectives from both inside and outside the structure [3].

At NMU, students have shown improved comprehension of core architectural principles such as spatial hierarchy, circulation flows, and light behaviour when engaging in immersive environments [4]. This improvement not only supports deeper learning but also reduces the likelihood of design errors and oversights during project development.

4.2. Increased Student Engagement and Motivation

Engagement is a cornerstone of effective learning, and immersive environments have been shown to enhance motivation, attention span, and learner satisfaction [6]. At NMU, students report higher enthusiasm for studio work when AVR is used, particularly during design reviews and peer critiques. The dynamic nature of AVR platforms encourages active learning, where students test, iterate, and present their ideas in a simulated real-world context.

This increased engagement is particularly relevant for Generation Z students, who are digital natives accustomed to interactive media [2]. AVR aligns with their cognitive preferences by offering gamified, responsive learning experiences that are both educational and exploratory.

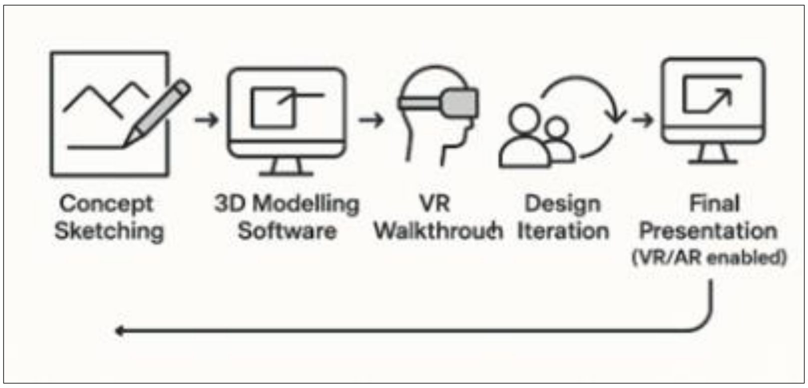

Figure 3 Students Engagement Workflow Using AVR

4.3. Improved Design Feedback and Critique Processes

The feedback process in architecture is traditionally dependent on paper-based drawings, printed models, or verbal critique. AVR enhances this process by making design intent visible and navigable, allowing reviewers to explore the student's model in 3D and provide spatially situated feedback [5]. At NMU, lecturers and peers can use AR overlays to annotate models, point out design inconsistencies, and test design alternatives in real time.

Such feedback loops are more immediate, collaborative, and contextual, improving the overall quality of studio discourse. Students gain a more accurate understanding of how their design decisions impact human interaction with space and structure.

4.4. Interdisciplinary Collaboration and Team Learning

AVR supports multi-user environments, allowing students from different disciplines to co-design and evaluate projects in real-time. NMU has leveraged this by encouraging collaboration between architecture, civil engineering, and construction management students, simulating real-world design workflows [4]. This approach promotes critical soft skills such as communication, teamwork, and systems thinking.

For instance, an architecture student might focus on form and experience, while a civil engineering student evaluates structural feasibility, and a construction management student assesses buildability all within a shared VR model. Such interdisciplinary interactions foster a holistic approach to built environment education.

4.5. Alignment with Industry and Technological Trends

The global design and construction industry is undergoing rapid digital transformation. Technologies like Building Information Modelling (BIM), digital twins, and parametric design increasingly rely on immersive platforms for simulation, coordination, and stakeholder communication. Exposure to AVR at the university level prepares students for this evolving professional landscape.

At NMU, industry partners have expressed interest in AVR-trained graduates who can operate tools such as Unity, Enscape, and VR walkthrough platforms for client presentations and stakeholder engagement [2]. This ensures that students are not only technically proficient but also professionally competitive upon graduation.

4.6. Research Development and Curriculum Innovation

The use of AVR at NMU has sparked research-based curriculum innovation, with staff investigating best practices for immersive learning. Findings have informed changes to course content, assessment methods, and studio culture. AVR has also led to increased academic output through publications, conference presentations, and cross-institutional collaborations [4].

Furthermore, the university has developed open-source AVR resources for broader use, including VR templates, AR exercises, and mobile-compatible modules. These tools support other institutions particularly those with fewer resources in adopting immersive design education.

4.7. Accessibility and Inclusion

Though AVR technologies are often associated with high cost, NMU has prioritised accessibility and social equity in its implementation. Through shared lab facilities, loan schemes, and mobile-ready AR tools, the institution ensures that students from diverse socio-economic backgrounds can participate in immersive learning experiences [1]. NMU's strategic focus on inclusion has become a model for how AVR can be scaled responsibly within the constraints of the South African education system.

This focus is particularly important in a country where digital inequality is a persistent barrier to equitable education. By creating low-bandwidth, offline-capable, and device-flexible solutions, NMU is helping to bridge the gap between urban and rural access to advanced digital education.

4.8. Contribution to Sustainable Design Practices

Lastly, AVR enables more sustainable design education by reducing reliance on physical materials like foam board, cardboard, and ink used in traditional model-making. Students can test and refine their ideas digitally before committing to physical production, aligning with both environmental goals and cost-efficiency [5]. This shift supports the teaching of sustainable thinking from the outset of architectural education.

Moreover, virtual simulations of energy performance, daylight analysis, and material behaviour help students develop environmentally responsive designs a key priority in both South African and global contexts.

The benefits of integrating AVR into architectural engineering education at NMU demonstrate the multifaceted potential of immersive technologies to revolutionize learning. From enhanced cognition and interdisciplinary teamwork to global employability and sustainable practice, the adoption of AVR yields outcomes that are academic, professional, and societal. As more South African institutions explore these technologies, NMU's inclusive and pedagogically sound model offers valuable lessons for nationwide and continental AVR adoption.

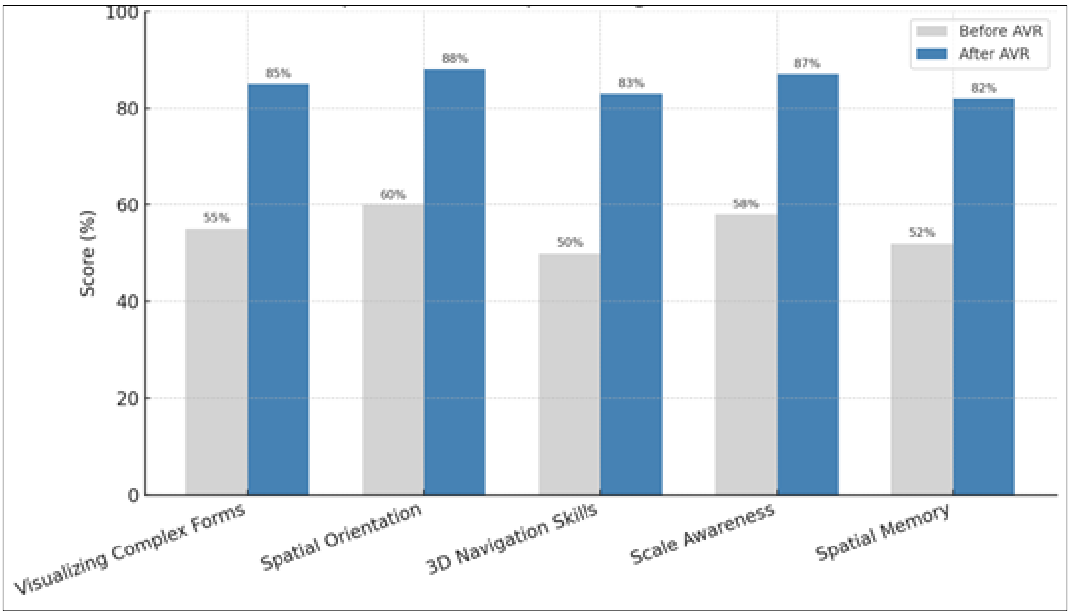

Figure 4 Spatial Cognition Improvement Chart – After AVR Use

The Chart illustrates the increase in students' spatial understanding after using AVR. Each category like "3D Navigation Skills" and "Scale Awareness" - shows a clear improvement in post-AVR scores, supporting the effectiveness of immersive technology in architectural education.

5. Challenges in Scaling AVR Integration

Despite the transformative potential of Augmented Virtual Reality (AVR) in architectural engineering education, its widespread adoption in South Africa remains limited due to several intersecting challenges. Institutions like Nelson Mandela University (NMU) have made commendable progress in deploying AVR, yet replicating this success on a national scale requires a critical examination of the systemic, technological, and pedagogical barriers that currently impede implementation. This section outlines six key challenges that constrain the full integration of AVR into architectural education across South African universities and colleges.

5.1. High Setup and Maintenance Costs

One of the most significant barriers to AVR adoption is the substantial financial investment required to establish and maintain immersive learning environments. Setting up a functional AVR studio typically demands high-spec computers, VR headsets (e.g., Oculus Quest or HTC Vive), software licenses (e.g., Enscape, Twinmotion, Unity), and dedicated physical space with adequate technical support and internet infrastructure [5]. For many South African institutions, particularly rural universities and historically disadvantaged colleges, these initial costs are prohibitive.

Even at NMU despite external support and institutional commitment cost remains a limiting factor. Regular hardware upgrades, staff training, and subscription renewals strain limited departmental budgets. Moreover, technical malfunctions, software compatibility issues, and the need for continuous updates make AVR integration a recurring financial obligation rather than a once-off capital expense [2].

5.2. Digital Inequality and Limited Student Access

South Africa's ongoing digital divide poses a substantial barrier to equitable AVR adoption. Many students, especially those from low-income households or rural areas, lack access to VR-capable personal devices or reliable broadband internet both prerequisites for engaging in immersive platforms from home [1]. This exclusion risks reproducing inequalities within the classroom, where only some students can fully participate in AVR-enhanced tasks.

Although NMU has attempted to mitigate this by offering shared studio access and exploring mobile-compatible AR alternatives, the issue persists. The challenge is not only technical but also social: without targeted support, AVR-enhanced education may become elitist, catering primarily to urban, tech-savvy students while marginalising others.

5.3. Curriculum Misalignment and Accreditation Gaps

Integrating AVR into architectural curricula often clashes with existing programme structures, which are rigidly governed by national accreditation standards, credit hour frameworks, and traditional assessment models [2]. Most architectural programmes in South Africa remain heavily grounded in 2D drafting, paper-based submissions, and fixed studio schedules, leaving little room for immersive learning experiments.

Furthermore, regulatory bodies such as the South African Council for the Architectural Profession (SACAP) have yet to formally endorse or integrate AVR competencies into graduate outcome criteria. This results in a misalignment between technological innovation and institutional accountability, deterring lecturers from prioritising AVR in their teaching [4].

5.4. Limited Technical Expertise and Staff Training

Another major challenge lies in the lack of training and confidence among academic staff in using AVR tools effectively. While younger faculty may be more digitally literate, many experienced lecturers—especially those trained in pre-digital or analogue design methods express discomfort or resistance toward integrating immersive technologies into their practice [6].

At NMU, targeted professional development workshops and collaborative teaching models have helped bridge this gap, but the demand for AVR-savvy educators far exceeds current capacity. Moreover, the fast-paced evolution of AR/VR platforms demands continuous upskilling, which many overburdened academics struggle to accommodate within their workloads [3].

5.5. Technological Fragmentation and Lack of Interoperability

The AVR ecosystem is rapidly expanding, with a wide array of platforms, devices, and software emerging every year. However, these tools are often technologically fragmented and lack interoperability, creating complications for curriculum planning and cross-platform learning. For instance, a VR environment built using Autodesk Revit with Enscape may not function seamlessly on Unity-based platforms or may require conversion tools that introduce rendering errors or compatibility issues.

This fragmentation imposes steep learning curves on students and staff, who must navigate a constantly shifting landscape of updates, software patches, and device-specific protocols. For institutions, it also complicates procurement decisions and long-term infrastructure planning, as standardised, future-proof solutions remain elusive [4].

5.6. Resistance to Pedagogical Change

Finally, AVR integration is often hindered by institutional and cultural resistance to pedagogical transformation. Architectural education, in particular, is deeply rooted in traditional studio culture, where hand-drawing, physical model-making, and face-to-face critiques have been revered for decades. Introducing AVR into this space requires not just technical adoption but a paradigm shift in teaching philosophy, learning objectives, and evaluation methods [2].

Some educators fear that immersive technologies may undermine core design skills, such as sketching and critical reflection, while others are sceptical of their pedagogical value in comparison to conventional tools. Overcoming this resistance requires robust evidence of impact, inclusive design of AVR curricula, and continuous dialogue between technologists and traditional educators.

While the benefits of AVR integration in architectural engineering are substantial, the pathway to full adoption in South African higher education is fraught with systemic challenges. These include prohibitive setup costs, persistent digital inequality, curriculum rigidity, limited staff expertise, platform incompatibility, and cultural resistance to innovation. As demonstrated by NMU's experience, overcoming these barriers requires a strategic, inclusive, and institution-wide approach one that recognises the complexity of educational transformation and prioritises long-term sustainability over quick technological fixes.

6. Global Implications and South Africa's Strategic Role

The global education landscape is undergoing a profound digital transformation, marked by increasing investment in immersive technologies such as Augmented Virtual Reality (AVR). As architectural engineering faces new demands for sustainable, smart, and responsive design, AVR offers unprecedented opportunities for experiential learning, collaborative design, and international knowledge exchange. While most of this innovation has been led by institutions in the Global North, South Africa's growing embrace of AVR especially in universities like Nelson Mandela University (NMU) signals its potential to become a key contributor to the global discourse on immersive education.

6.1. South Africa as an Emerging Innovator in Immersive Learning

South Africa is uniquely positioned to bridge the digital divide between high-income and low-income educational systems. Its universities operate in both technologically advanced and resource-constrained contexts, making them fertile ground for innovations that are adaptable, inclusive, and scalable. The implementation of AVR at NMU exemplifies how immersive education can be reimagined for the Global South not as a luxury, but as a strategic necessity for enhancing educational access, equity, and impact [2].

By developing low-cost, mobile-ready AVR content, South African institutions can contribute open-access immersive learning models that are relevant for other countries across Africa, Latin America, and Southeast Asia facing similar constraints. In this regard, NMU's Virtual Architecture Teaching Programme (VATP) can serve as a regional benchmark for context-responsive innovation, where digital transformation is not only top-down but also grassroots and pedagogically intentional [4].

6.2. Catalysing Pan-African Collaboration and Knowledge Sharing

The growth of AVR in South Africa can also catalyse continental collaboration. Institutions such as NMU, the University of Cape Town, and the University of the Witwatersrand are increasingly engaging in cross-border partnerships, using AVR for joint studios, knowledge exchanges, and design research. These initiatives promote South–South academic networks, reducing reliance on Northern institutions for technological models.

Furthermore, AVR offers a platform to digitally preserve and share African architectural heritage, which is often under-documented. By building immersive libraries of indigenous and vernacular architecture, South African universities can contribute to global decolonisation efforts in design education highlighting African knowledge systems within an immersive, shareable format [2].

6.3. Training Globally Competitive Graduates

The global design and construction industry is rapidly embracing technologies such as Building Information Modelling (BIM), digital twins, parametric design, and real-time simulation. These innovations are no longer confined to architecture firms in London, Berlin, or Tokyo they are becoming standard practice worldwide. Therefore, South African graduates must be equipped with digital competencies that match international benchmarks [5].

AVR plays a vital role in this process. Students trained using immersive tools are better prepared for interdisciplinary workflows, stakeholder engagement, and international collaboration. NMU's curriculum innovations have shown that early exposure to AVR strengthens career readiness, enabling graduates to work confidently across borders, both remotely and in hybrid environments [3].

6.4. Contributing to the Global Research Agenda on AVR in Education

South Africa's growing involvement in immersive education also enriches the global research discourse. Most published research on AVR in education originates from Europe, North America, or East Asia, where contexts differ significantly in terms of infrastructure, pedagogy, and access. Research emerging from South African universities focused on affordable implementation, digital inclusion, and pedagogical adaptation adds critical diversity to the field.

NMU, for example, has begun publishing studies on the integration of AVR in resource-constrained design studios, lecturer training for immersive teaching, and the use of AR in rural student outreach [4]. Such research not only advances the theoretical understanding of AVR but also provides practical solutions for underfunded institutions globally. In this way, South Africa becomes not just a consumer but a producer of knowledge in the immersive education space.

6.5. Supporting Sustainable Development Goals through Education

The integration of AVR in South African architectural education also contributes to several United Nations Sustainable Development Goals (SDGs) particularly:

- SDG 4: Quality Education – by enhancing learning outcomes and increasing student engagement through immersive technologies.
- SDG 9: Industry, Innovation, and Infrastructure – by preparing graduates to contribute to smart infrastructure and digital innovation.
- SDG 11: Sustainable Cities and Communities – by training architects and engineers to design more inclusive, resilient urban environments using AVR simulations.
- SDG 17: Partnerships for the Goals – by fostering international collaboration in education and research.

As South Africa aligns its higher education priorities with global development frameworks, AVR becomes a strategic educational technology, supporting broader national and international transformation agendas [2][5].

South Africa has the opportunity and the obligation to shape the global future of immersive education in architectural engineering. Through its pioneering initiatives, such as NMU's VATP, the country is showing that technological innovation can be both inclusive and globally impactful. By building partnerships, publishing locally grounded research, and training digitally empowered graduates, South African institutions can position themselves as thought leaders in AVR-based learning. As global interest in immersive education continues to rise, the South African experience offers vital insights into how innovation can be leveraged to support equity, excellence, and global relevance.

7. Recommendations

To maximize the impact of Augmented Virtual Reality (AVR) in South African architectural engineering education—and to contribute meaningfully to global innovation and equity in immersive learning—the following recommendations are proposed:

7.1. Institutional Investment and Strategic Planning

South African universities and technical colleges should develop comprehensive AVR implementation strategies that go beyond ad hoc technology purchases. Institutions must treat AVR as a long-term pedagogical transformation, not just a temporary technological experiment. This includes:

- Allocating sustained budgets for hardware, software, and technical support.
- Creating dedicated immersive learning labs or studios, particularly within architecture and engineering faculties.
- Appointing AVR coordinators or digital learning specialists to manage integration and curriculum alignment [4].
- Developing mobile-compatible and low-bandwidth alternatives for students with limited access, thus ensuring inclusive adoption [1].

The success of NMU's Virtual Architecture Teaching Programme (VATP) illustrates the importance of institutional commitment and careful infrastructure planning to support immersive education at scale.

7.2. Curriculum Redesign and Accreditation Alignment

Higher education institutions must restructure architectural engineering curricula to formally incorporate AVR competencies as part of core learning outcomes. This involves:

- Introducing AVR-supported modules from the first year of study to build fluency early.
- Embedding immersive activities into design studios, technical subjects, and presentation formats.
- Working with regulatory bodies such as SACAP and the Council on Higher Education (CHE) to ensure that AVR-related skills are recognised in programme accreditation and graduate exit-level outcomes [2].

This curriculum integration should be supported by assessment tools that can capture digital design literacy, immersive interaction, and 3D communication.

7.3. Lecturer Upskilling and Community of Practice Development

A major bottleneck in AVR integration is the limited digital preparedness among academic staff. Institutions should:

- Offer structured training programmes for educators in immersive design platforms such as SimLab, Enscape, Unity, Twinmotion, and AR mobile tools.
- Establish communities of practice, where lecturers can share knowledge, test new tools, and co-develop AVR learning content.
- Promote interdisciplinary collaboration between architecture, engineering, and ICT departments to expand the creative and technical boundaries of immersive education [3].

Investment in educator development is critical to building a sustainable, self-sufficient immersive education ecosystem.

7.4. Government Support and Policy Advocacy

The Department of Higher Education and Training (DHET) should recognize AVR as a strategic educational technology and support its rollout through national frameworks, such as the Digital Learning Policy and the University Capacity Development Programme (UCDP). Specific actions include:

- Funding pilot projects at historically disadvantaged institutions.
- Subsidizing open-source AVR resources that can be used across the sector.
- Including immersive technologies in the National Qualification Framework (NQF) competencies related to design and engineering.
- Incentivizing research and innovation grants for immersive learning studies across South African universities [2].

National support is essential to reduce inequity between well-resourced and under-resourced institutions, particularly in the rural provinces.

7.5. Industry Partnerships and Professional Integration

AVR adoption in education should mirror the demands of a digitally transforming built environment industry. Institutions should:

- Establish partnerships with AVR software developers and architecture/engineering firms to align educational content with real-world applications.
- Create student internship opportunities within firms using immersive tools like BIM-VR, virtual walkthroughs, and digital twins.
- Involve practicing professionals in studio critiques and design reviews conducted through VR platforms to model authentic industry workflows [5].

This will ensure graduates are workplace-ready and can lead digital innovation in both local and international practices.

7.6. Research, Monitoring, and Continuous Evaluation

Finally, the impact of AVR on architectural education must be continuously studied and documented. Universities, in collaboration with education researchers, should:

- Conduct longitudinal studies tracking learning outcomes, design quality, and graduate employability in AVR-enhanced programmes.
- Publish case studies and comparative data to inform sector-wide best practices.
- Explore socio-technical impacts, particularly how AVR affects student identity, participation, and access across gender, race, and class [2].
- The contribution of South African institutions like NMU to the global research landscape will ensure that evidence-based practices underpin immersive educational transformation.

For South Africa to lead in the equitable and impactful use of AVR in architectural engineering education, a multi-level strategy is essential. Institutional investments must be matched by pedagogical reform, national policy alignment, and ongoing professional development. Industry and academic partnerships can enhance relevance, while continuous research ensures sustainability. The pioneering example of Nelson Mandela University provides a compelling case study but for meaningful transformation, these recommendations must be scaled, localised, and sustained across the national education system.

8. Conclusion

This study has demonstrated the transformative potential of Augmented Virtual Reality (AVR) within South African architectural engineering education, emphasizing both local innovation and global relevance. The integration of immersive technologies particularly at Nelson Mandela University (NMU) offers a compelling model for how digital tools can enhance spatial understanding, design collaboration, and professional readiness in a resource-constrained yet rapidly digitizing educational landscape.

Research shows that Augmented and Virtual Reality (AVR) significantly enhances students' visual-spatial skills, engagement levels, and ability to refine design solutions capabilities that traditional 2D or physical tools struggle to match. AVR also promotes interdisciplinary collaboration, aligns academic training with modern industry practices, and supports innovative teaching methods that resonate with Generation Z learners, who are inherently comfortable with digital technologies.

Despite its potential, the adoption of AVR faces notable barriers such as high implementation costs, unequal access to digital resources, inflexible curricula, and the ongoing need for faculty training. NMU experience highlights that addressing these challenges demands a strong institutional commitment, careful strategic planning, inclusive access initiatives, and robust partnerships among academic institutions, government bodies, and industry stakeholders.

On a broader scale, South Africa's engagement with AVR situates it as a vital contributor to global conversations on immersive education, particularly by offering context-specific innovations relevant to other Global South nations. Through open research, collaborative networks, and scalable technology models, South African universities can help democratize access to high-quality architectural education and foster sustainable development goals aligned with digital inclusion and infrastructure innovation.

Augmented Virtual Reality represents more than a technological enhancement it is a pedagogical and socio-economic catalyst capable of reshaping architectural engineering education in South Africa and beyond. To fully realize this potential, stakeholders must embrace a coordinated, long-term strategy encompassing investment, curriculum reform, capacity building, policy advocacy, and research. Only then can immersive learning environments serve as equitable platforms for nurturing the next generation of architects and engineers equipped to address the complex challenges of the 21st century.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Aesaert, K., van Braak, J., van Nijlen, D., and Vanderlinde, R. (2015). Primary school pupils' ICT competencies: Exploring the role of ICT self-efficacy and attitudes. Computers in Human Behavior, 51, 161–170. https://doi.org/10.1016/j.chb.2015.04.005

[2] Brown, D. (2022). Digital transitions in African architecture: Industry, education, and innovation. South African Journal of Architecture and Education, 10(2), 45–60.

[3] Marques, B., Sousa Santos, B., and Dias, P. (2021). Ten years of immersive education: Overview of a virtual and augmented reality course at postgraduate level. Computers and Education, 172, 104257. https://doi.org/10.1016/j.compedu.2021.104257

[4] Nelson Mandela University (NMU). (2023). Virtual Architecture Teaching Programme (VATP). Faculty of Engineering, the Built Environment and Technology.

[5] Oleseni, M. P., Olawade, D. B., Afolalu, T. D., Olatoye, O. E., and Akinwalere, I. G. (2019). Augmented virtual reality in education and the field of medicine for global impact. International Journal of Advanced Research, 7(12), 344–353. https://doi.org/10.21474/IJAR01/10256

[6] Prensky, M. (2001). Digital natives, digital immigrants. On the Horizon, 9(5), 1–6. https://doi.org/10.1108/10748120110424816