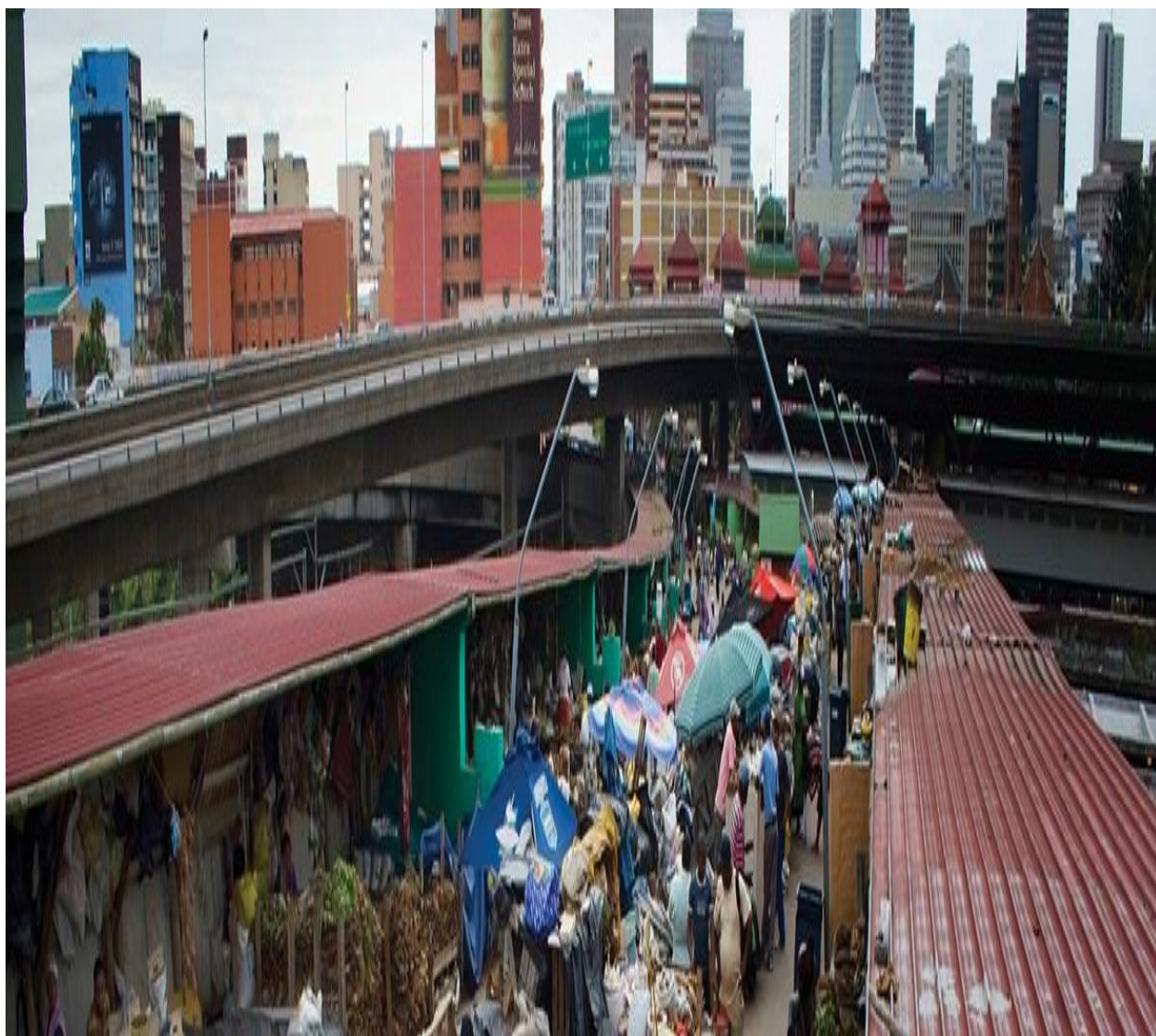


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RESEARCH ARTICLE

Sustainable Experience Design in Mixed Reality Exhibitions: A Case Study Framework

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The integration of Mixed Reality (MR) technologies into exhibition design has redefined contemporary experience creation, enabling immersive, interactive, and multisensory environments. However, the increasing reliance on energy-intensive digital systems and rapidly evolving hardware raises critical concerns regarding environmental sustainability, technological obsolescence, and ethical design. This study investigates the intersection of sustainable design principles and experience design within MR exhibitions through a qualitative research approach based on secondary data analysis. Drawing upon theoretical perspectives from experience economy theory, sustainable design theory, and human-centred design, the research develops a comprehensive framework for sustainable MR exhibition design. The findings reveal that sustainability in MR environments is multidimensional, encompassing ecological efficiency, experiential quality, technological adaptability, and socio-cultural inclusivity. The study argues that meaningful user experiences can be achieved without excessive technological complexity by emphasising narrative engagement, efficient system design, and lifecycle thinking. The proposed case study framework offers practical guidelines for designers and curators to balance immersive engagement with environmental responsibility. This research contributes to the emerging discourse on sustainable digital environments and provides a foundation for future empirical investigations in immersive experience design.

Keywords: mixed reality, sustainable design, experience design, immersive exhibitions, digital sustainability, human-centred design, circular design

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1. Introduction

The rapid evolution of immersive technologies has significantly transformed the landscape of exhibition design, particularly through the emergence of Mixed Reality (MR). MR, situated along the continuum between physical and virtual environments, integrates real-world and digital elements to create interactive and immersive user experiences (Milgram & Kishino, 1994). This technological advancement has redefined how cultural institutions, museums, galleries, and commercial exhibitions engage with audiences, enabling dynamic storytelling, multisensory interaction, and personalised content delivery. As a result, MR has become a critical tool in shaping contemporary experience design.

In recent years, the growing adoption of MR technologies has been driven by advancements in hardware, software, and computational capabilities. Devices such as head-mounted displays, spatial computing systems, and sensor-based interfaces have enabled designers to create hybrid environments where users can seamlessly interact with both physical and digital objects (Billinghurst et al., 2015). These developments align with broader shifts toward experiential consumption, where audiences seek meaningful and memorable interactions rather than passive observation. The concept of the “experience economy,” as articulated by Pine and Gilmore (1999), emphasises the importance of designing engaging experiences that create emotional and cognitive value for users.

However, while MR technologies offer unprecedented opportunities for enhancing user engagement, they also introduce significant sustainability challenges. Traditional sustainability discourse in design has primarily focused on material usage, energy efficiency, and environmental impact. In contrast, the sustainability of digital and immersive environments encompasses a broader range of considerations, including the energy consumption of computational systems, the lifecycle of electronic devices, and the environmental implications of data storage and processing (Hilty & Aebischer, 2015). MR exhibitions, which often rely on high-performance computing and specialised hardware, can contribute to increased carbon emissions and electronic waste if not designed responsibly.

Moreover, the rapid pace of technological innovation in MR exacerbates issues of obsolescence. Devices and software platforms frequently become outdated within short periods, leading to increased resource consumption and waste generation. This phenomenon poses a critical challenge for designers and institutions seeking to balance innovation with sustainability. As Belkhir and Elmeligi (2018) note, the global information and communication technology (ICT) sector is a growing contributor to greenhouse gas emissions, highlighting the need for sustainable practices in digital design.

In addition to environmental concerns, MR exhibitions raise important questions related to social and cultural sustainability. Experience design in MR must account for issues of accessibility, inclusivity, and ethical

engagement. For instance, not all users have equal access to MR technologies due to economic, physical, or technological barriers. Furthermore, immersive environments can influence user perceptions and behaviours, necessitating careful consideration of ethical design principles (Norman, 2013). Sustainable MR design, therefore, extends beyond ecological considerations to encompass social responsibility and user well-being.

The intersection of sustainability and experience design presents both challenges and opportunities. On one hand, the pursuit of highly immersive experiences often prioritises technological sophistication and sensory richness, potentially increasing resource consumption. On the other hand, sustainable design principles can enhance user experiences by promoting simplicity, efficiency, and meaningful engagement. For example, minimalist design approaches can reduce cognitive overload while also minimising computational requirements, thereby contributing to both experiential quality and sustainability (Hassenzahl, 2010).

Despite the growing importance of sustainability in design, there remains a notable gap in the literature regarding its application in MR exhibition contexts. Existing research on MR primarily focuses on technological capabilities, user experience, and application domains, with limited attention to environmental and social impacts. Similarly, studies on sustainable design often emphasise physical products and built environments, overlooking the unique challenges associated with digital and

immersive systems. This gap underscores the need for an integrated framework that addresses both sustainability and experience design in MR exhibitions.

This study aims to address this gap by developing a case study framework for sustainable experience design in MR exhibitions. By synthesising insights from existing literature, case studies, and theoretical perspectives, the research seeks to identify key dimensions and strategies for designing environmentally responsible and engaging MR experiences. The study adopts a qualitative research methodology based on secondary data analysis, enabling a comprehensive examination of current practices and emerging trends.

The significance of this research lies in its interdisciplinary approach, integrating concepts from experience economy theory, sustainable design theory, and human-centred design. By combining these perspectives, the study provides a holistic understanding of sustainable MR exhibition design, emphasising the interdependence of ecological, technological, and experiential factors. The proposed framework aims to guide designers, curators, and policymakers in creating MR exhibitions that are not only innovative and engaging but also environmentally and socially responsible.

In conclusion, the integration of sustainability into MR experience design represents a critical frontier in contemporary exhibition practice. As immersive technologies continue to evolve, it is essential to develop design approaches that balance innovation with responsibility. This study contributes to this endeavour by offering a

comprehensive framework for sustainable MR exhibitions, paving the way for future research and practice in this emerging field.

2. Literature

Mixed Reality (MR) has emerged as a transformative technology in exhibition design, enabling the integration of physical and digital environments into cohesive experiential spaces. The foundational work of Milgram and Kishino (1994) conceptualises MR as part of a reality–virtuality continuum, encompassing both augmented reality (AR) and virtual reality (VR). This framework has been instrumental in understanding how MR technologies facilitate varying degrees of immersion and interaction.

In exhibition contexts, MR enhances visitor engagement by enabling interactive storytelling and contextualised information delivery. For example, AR applications allow users to overlay digital content onto physical artefacts, providing additional layers of interpretation and engagement (Tom Dieck & Jung, 2017). Similarly, VR environments enable users to explore reconstructed historical sites or inaccessible locations, thereby expanding the scope of exhibition experiences (Sylaiou et al., 2010). These capabilities have been widely adopted in museums and cultural institutions, where MR is used to attract diverse audiences and enhance educational outcomes.

Billinghurst et al. (2015) highlight the importance of interaction design in MR systems, emphasising the role of intuitive interfaces and real-time responsiveness in

creating effective user experiences. The integration of spatial computing technologies further enhances the realism and immersion of MR environments, allowing users to interact with digital objects in three-dimensional space. This shift from passive observation to active participation aligns with broader trends in experience design, where user engagement and interactivity are central.

However, the adoption of MR technologies in exhibitions is not without challenges. Technical limitations, such as latency, resolution, and tracking accuracy, can affect user experience and accessibility. Additionally, the high cost of MR hardware and infrastructure can limit widespread implementation, particularly in resource-constrained settings. These challenges underscore the need for sustainable and scalable design approaches that balance technological capabilities with practical considerations.

2.1 Sustainable Design Principles in Digital Contexts

Sustainable design has traditionally focused on minimising environmental impact through efficient use of resources and reduction of waste. McDonough and Braungart's (2002) cradle-to-grave framework emphasises the importance of designing products and systems that can be continuously reused or recycled, thereby eliminating waste. While this approach has been widely applied in industrial and architectural design, its application in digital and immersive environments remains relatively underexplored.

In the context of digital systems, sustainability encompasses both direct and indirect environmental impacts. Direct impacts include the energy consumption of devices and infrastructure, while indirect impacts involve the lifecycle of hardware and the environmental costs of production and disposal (Hilty et al., 2006). MR exhibitions, which rely on high-performance computing and specialised hardware, are particularly energy-intensive, raising concerns about their environmental footprint.

Recent research has highlighted the growing environmental impact of the ICT sector. Belkhir and Elmeligi (2018) estimate that ICT could account for up to 14% of global greenhouse gas emissions by 2040 if current trends continue. This projection underscores the urgency of integrating sustainability into digital design practices. Strategies for sustainable digital design include optimising software efficiency, reducing data transmission, and utilising renewable energy sources.

Bhamra and Lofthouse (2016) argue that sustainable design must also consider user behaviour and experience. For example, designing systems that encourage efficient usage patterns can significantly reduce energy consumption. In MR exhibitions, this may involve optimising interaction design to minimise unnecessary computational processes or encouraging shorter session durations without compromising user engagement.

2.2 Experience Design and User Engagement

Experience design is a multidisciplinary field that focuses on creating meaningful interactions between users and systems. Pine and Gilmore's (1999) experience economy framework identifies four realms of experience: entertainment, education, escapism, and aesthetics, which provide a useful lens for analysing MR exhibitions. These dimensions highlight the diverse ways in which users engage with immersive environments.

Hassenzahl (2010) emphasises the importance of designing for user experience (UX), rather than merely focusing on functionality. According to this perspective, successful design must address users' emotional and psychological needs, creating experiences that are not only usable but also enjoyable and meaningful. In MR exhibitions, this involves careful consideration of narrative structure, interaction design, and sensory engagement.

The integration of MR technologies into experience design enables new forms of engagement, such as embodied interaction and spatial storytelling. Users can navigate virtual environments, manipulate digital objects, and participate in interactive narratives, creating a sense of presence and immersion. However, these experiences can also be cognitively demanding, requiring designers to balance complexity with usability.

From a sustainability perspective, experience design plays a crucial role in shaping user behaviour and perceptions. For example,

immersive experiences can be used to raise awareness about environmental issues, promoting sustainable attitudes and behaviours. At the same time, designers must ensure that the creation of such experiences does not undermine sustainability goals through excessive resource consumption.

2.3 Sustainability Challenges in Immersive Media

The sustainability of immersive media is an emerging area of research, reflecting the increasing prevalence of technologies such as MR, VR, and AR. These technologies require significant computational resources, including high-performance graphics processing and real-time data processing. As a result, they contribute to increased energy consumption and carbon emissions.

Hilty and Aebischer (2015) highlight the environmental implications of ICT systems, emphasising the need for lifecycle assessment and sustainable design practices. In MR exhibitions, this includes considering the environmental impact of hardware production, usage, and disposal. The rapid pace of technological innovation further complicates this issue, as devices quickly become obsolete and require replacement.

Another challenge is the scalability of MR systems. Large-scale exhibitions may require multiple devices, servers, and network infrastructure, increasing resource consumption. Cloud-based solutions can mitigate some of these challenges by centralising computational processes, but they also introduce additional energy demands associated with data centres.

Despite these challenges, immersive media also offers opportunities for sustainability. For example, virtual exhibitions can reduce the need for physical travel, thereby lowering carbon emissions. Additionally, digital content can be reused and adapted across different contexts, reducing the need for new resources.

2.4 Toward Sustainable MR Exhibition Design

The integration of sustainability into MR exhibition design requires a holistic approach that considers ecological, technological, and experiential factors. Existing literature suggests several key strategies:

- **Lifecycle thinking:** Designing systems with long-term use and adaptability in mind
- **Energy efficiency:** Optimising hardware and software to reduce energy consumption
- **Modularity:** Enabling components to be upgraded or replaced without discarding entire systems
- **User-centred design:** Ensuring accessibility and inclusivity

Norman (2013) emphasises that human-centred design is essential for creating sustainable systems, as it ensures that technologies are aligned with user needs and behaviours. In MR exhibitions, this involves designing experiences that are engaging, accessible, and meaningful, while also minimising environmental impact.

In summary, the literature highlights the need for integrated frameworks that address both sustainability and experience design in MR

exhibitions. While significant progress has been made in understanding MR technologies and sustainable design principles, there remains a gap in their combined application. This study seeks to address this gap by developing a comprehensive framework for sustainable MR exhibition design.

3. Theoretical Framework

The development of a sustainable experience design framework for Mixed Reality (MR) exhibitions requires an interdisciplinary theoretical foundation that integrates perspectives from experience design, sustainability studies, and human-centred interaction. This study adopts a composite theoretical framework drawing upon Experience Economy Theory, Sustainable Design Theory, and Human-Centred Design (HCD). The integration of these perspectives enables a holistic understanding of how immersive experiences can be designed to balance user engagement with environmental and social responsibility.

3.1 Experience Economy Theory

Experience Economy Theory, as proposed by Pine and Gilmore (1999), posits that economic value has evolved from commodities and goods to services and, ultimately, experiences. In this paradigm, organisations create value by engaging individuals in memorable and meaningful ways. This theoretical perspective is particularly relevant to MR exhibitions, where immersive technologies are employed to create engaging and participatory environments.

Pine and Gilmore (1999) identify four realms of experience: entertainment, education, escapism, and aesthetics, which serve as a useful framework for analysing MR exhibition design. MR technologies enable the seamless integration of these realms by offering interactive storytelling, experiential learning, and sensory immersion. For instance, MR exhibitions can transform passive viewers into active participants, allowing them to explore narratives, manipulate digital objects, and engage with content in real time (Billinghurst et al., 2015).

However, the pursuit of highly immersive experiences often prioritises technological sophistication and sensory richness, potentially leading to increased resource consumption. From a sustainability perspective, it is essential to critically evaluate how experiential value is created and whether it can be achieved through more resource-efficient means. Hassenzahl (2010) argues that meaningful user experiences are not solely dependent on technological complexity but can also be achieved through simplicity, clarity, and emotional resonance. This insight suggests that sustainable MR design should focus on optimising experiential quality rather than maximising technological intensity.

3.2 Sustainable Design Theory

Sustainable Design Theory provides the ecological foundation for this study, emphasising the need to minimise environmental impact while maximising social and economic value. The cradle-to-cradle framework developed by McDonough and Braungart (2002) is particularly influential, advocating for systems that

eliminate waste by designing products and processes for continuous reuse and regeneration.

In the context of MR exhibitions, sustainable design extends beyond physical materials to include digital infrastructure, energy consumption, and the lifecycle of technological systems. Hilty et al. (2006) highlight that information and communication technologies (ICT) have both direct and indirect environmental impacts, including energy use during operation and the environmental costs of manufacturing and disposal. MR systems, which rely on high-performance computing and specialised hardware, are particularly resource-intensive, necessitating careful consideration of their environmental footprint.

Lifecycle thinking is a central principle of sustainable design, emphasising the importance of considering the entire lifespan of a system, from production and use to disposal and reuse (Bhamra & Lofthouse, 2016). In MR exhibitions, this involves designing hardware and software systems that are durable, adaptable, and capable of being updated or repurposed over time. Modular design approaches, for example, allow components to be upgraded without replacing entire systems, thereby reducing waste and resource consumption.

Another key aspect of sustainable design is the integration of circular economy principles, which aim to close resource loops and minimise waste. In MR contexts, this can be achieved through the reuse of digital assets, optimisation of data storage, and adoption of energy-efficient coding practices. Belkhir and Elmeligi (2018) emphasise the

growing environmental impact of the ICT sector, underscoring the need for sustainable practices in digital design.

3.3 Human-Centred Design (HCD)

Human-Centred Design (HCD) focuses on designing systems that prioritise the needs, behaviours, and experiences of users (Norman, 2013). In MR exhibitions, HCD is essential for ensuring that technologies are accessible, intuitive, and meaningful. This perspective aligns with the principles of experience design, emphasising the importance of usability, emotional engagement, and user satisfaction.

HCD also plays a critical role in promoting sustainability by influencing user behaviour and interaction patterns. For example, intuitive interfaces can reduce cognitive load and minimise the need for repeated interactions, thereby improving efficiency and reducing energy consumption. Additionally, inclusive design practices ensure that MR exhibitions are accessible to diverse audiences, including individuals with disabilities or limited technological literacy.

From a sustainability perspective, HCD extends to considerations of user well-being and ethical engagement. Immersive technologies can have psychological and physiological effects, such as motion sickness or cognitive fatigue, which must be addressed through careful design (Hassenzahl, 2010). Sustainable MR design, therefore, involves creating experiences that are not only engaging but also safe, comfortable, and ethically responsible.

3.4 Integrated Theoretical Model

The integration of Experience Economy Theory, Sustainable Design Theory, and Human-Centred Design results in a multi-dimensional framework for sustainable MR exhibition design. This framework comprises four interrelated dimensions:

- **Experiential Dimension** – Focuses on user engagement, immersion, and emotional impact, drawing from experience economy theory.
- **Ecological Dimension** – Addresses environmental impact, resource efficiency, and lifecycle considerations, informed by sustainable design theory.
- **Technological Dimension** – Emphasises system efficiency, adaptability, and scalability, bridging sustainability and technological innovation.
- **Socio-Cultural Dimension** – Considers accessibility, inclusivity, and ethical implications, grounded in human-centred design principles.

These dimensions are interconnected and must be considered holistically in the design of MR exhibitions. For example, enhancing experiential quality should not come at the expense of ecological sustainability, and technological innovation must be aligned with user needs and social responsibility.

In summary, the theoretical framework provides a comprehensive foundation for analysing and designing sustainable MR exhibitions. By integrating multiple perspectives, it enables a nuanced understanding of the complex relationships

between technology, experience, and sustainability.

4. Research Methodology

This study adopts a qualitative research design to explore the integration of sustainability and experience design in Mixed Reality (MR) exhibitions. Qualitative research is particularly suitable for this study as it enables an in-depth exploration of complex phenomena, including user experience, design practices, and sustainability considerations (Creswell & Poth, 2018). Given the exploratory nature of the research, a qualitative approach allows for the synthesis of diverse perspectives and the development of a conceptual framework.

The study is based on secondary data analysis, which involves the systematic examination of existing literature, case studies, and industry reports. Secondary data analysis is appropriate for this research because it provides access to a wide range of information on MR technologies and sustainable design practices, enabling a comprehensive understanding of the subject (Johnston, 2017). Additionally, the use of secondary data allows for the identification of patterns and trends across different contexts, contributing to the development of a generalised framework.

4.1 Data Sources and Collection

The data for this study were collected from multiple secondary sources to ensure breadth and depth of analysis. These sources include:

- **Peer-reviewed academic journals**, such as *Journal of Cleaner Production*, *Computers & Education*,

and *Museum Management and Curatorship*

- **Conference proceedings** related to human-computer interaction (HCI), virtual reality (VR), and augmented reality (AR)
- **Industry reports** from museum technology organisations and digital design firms
- **Documented case studies** of MR exhibitions in museums, galleries, and commercial settings

The selection of sources was guided by relevance, credibility, and recency. Priority was given to peer-reviewed publications and widely cited works to ensure the reliability of the data. Additionally, interdisciplinary sources were included to capture the multifaceted nature of MR exhibition design.

The data collection process involved systematic searching using academic databases such as Google Scholar, Scopus, and Web of Science. Keywords used in the search included “Mixed Reality exhibitions,” “sustainable design,” “immersive experience design,” and “digital sustainability.” Relevant articles and reports were identified, reviewed, and organised for analysis.

4.2 Data Analysis Method

The study employs thematic analysis as the primary method for analysing the collected data. Thematic analysis is a widely used qualitative method for identifying, analysing, and interpreting patterns within data (Braun & Clarke, 2006). This method is particularly suitable for synthesising diverse sources of information and developing conceptual frameworks.

The analysis followed a six-phase process:

- **Familiarisation with Data:** The researcher reviewed all collected sources to gain a comprehensive understanding of the content.
- **Initial Coding:** Key concepts and themes related to MR design, sustainability, and user experience were identified and coded.
- **Theme Development:** Codes were grouped into broader themes, such as ecological sustainability, experiential quality, and technological adaptability.
- **Theme Review:** Themes were refined and validated through comparison across multiple sources.
- **Theme Definition:** Clear definitions and boundaries for each theme were established.
- **Synthesis:** The themes were integrated into a cohesive framework for sustainable MR exhibition design.

This systematic approach ensures that the analysis is rigorous, transparent, and replicable.

4.3 Case Study Approach

Although the study relies on secondary data, it incorporates a case study approach by analysing documented examples of MR exhibitions. Case studies provide valuable insights into real-world applications of MR technologies and sustainable design practices (Yin, 2018). By examining multiple case studies, the research identifies best practices, challenges, and opportunities for sustainable MR design.

The case study approach enables the exploration of context-specific factors, such as institutional goals, technological infrastructure, and audience demographics. This contextual understanding is essential for developing a practical and adaptable framework.

4.4 Validity and Reliability

Ensuring the validity and reliability of qualitative research is critical for establishing the credibility of findings. This study employs several strategies to enhance rigour:

- **Data triangulation:** Multiple sources of data were used to corroborate findings and reduce bias (Creswell & Poth, 2018).
- **Use of established theories:** The integration of well-established theoretical frameworks enhances the validity of the analysis.
- **Transparent methodology:** The research process is clearly documented, allowing for replication and verification.
- **Critical evaluation of sources:** Only credible and relevant sources were included in the analysis.

These measures contribute to the trustworthiness and robustness of the research.

4.5 Ethical Considerations

As this study is based on secondary data, it does not involve direct interaction with human participants. However, ethical considerations remain important, particularly in the selection and use of sources. All sources are properly cited in accordance with

APA (7th ed.) guidelines, ensuring academic integrity and avoiding plagiarism.

Additionally, the study considers the ethical implications of MR technologies, including issues related to user privacy, accessibility, and psychological impact. These considerations are integrated into the analysis and framework development (Mannan & Farhana, 2026).

4.6 Limitations of the Methodology

Despite its strengths, the methodology has certain limitations. The reliance on secondary data means that the findings are dependent on the quality and scope of existing literature. Additionally, the absence of primary data limits the ability to capture firsthand user experiences and perspectives.

Future research could address these limitations by incorporating empirical methods, such as user studies, surveys, or experimental designs, to validate and refine the proposed framework.

In summary, the qualitative research methodology employed in this study provides a robust foundation for exploring sustainable experience design in MR exhibitions. Through systematic secondary data analysis and thematic synthesis, the study develops a comprehensive framework that integrates theoretical insights and practical considerations. The methodology ensures rigour, transparency, and relevance, contributing to the overall validity of the research.

5. Findings and Analysis

The analysis of secondary data, including academic literature, documented case studies, and industry reports, reveals that sustainable experience design in Mixed Reality (MR) exhibitions is shaped by the dynamic interplay of ecological, experiential, technological, and socio-cultural factors. This section synthesises these findings into key thematic dimensions, providing a comprehensive understanding of the opportunities and challenges associated with sustainable MR exhibition design.

5.1 Ecological Sustainability in MR Systems

A central finding of this study is that ecological sustainability remains an underdeveloped yet critical dimension of MR exhibition design. While MR technologies are often celebrated for their immersive capabilities, their environmental impact is frequently overlooked. The energy-intensive nature of MR systems, including high-performance computing, real-time rendering, and sensor-based interaction, contributes significantly to carbon emissions (Hilty & Aebischer, 2015).

Belkhir and Elmeligi (2018) estimate that the ICT sector could account for up to 14% of global greenhouse gas emissions by 2040, highlighting the urgency of integrating sustainability into digital design practices. MR exhibitions, which rely on both hardware (e.g., head-mounted displays, motion sensors) and software infrastructure (e.g., cloud computing, data processing), contribute to this environmental burden.

Another critical issue is electronic waste (e-waste) generated by MR hardware. The rapid pace of technological innovation leads to frequent upgrades and replacements, resulting in short product lifecycles. This phenomenon is exacerbated by proprietary hardware ecosystems, which limit compatibility and reuse. From a lifecycle perspective, the production, use, and disposal of MR devices must be carefully considered to minimise environmental impact (Bhamra & Lofthouse, 2016).

Despite these challenges, the findings indicate that sustainable practices can be integrated into MR design. Strategies such as energy-efficient coding, optimisation of rendering processes, and the use of renewable energy sources can significantly reduce the environmental footprint of MR exhibitions. Additionally, modular hardware design and open-source platforms can extend the lifespan of devices and reduce waste.

5.2 Experiential Quality and Resource Efficiency

A key tension identified in the analysis is the perceived trade-off between experiential richness and sustainability. MR exhibitions are often designed to maximise immersion through high-resolution graphics, complex interactions, and multisensory engagement. However, these features typically require substantial computational resources, raising concerns about energy consumption and sustainability.

Contrary to this assumption, the findings suggest that experiential quality does not necessarily depend on technological intensity. Hassenzahl (2010) argues that

meaningful experiences are shaped by emotional engagement, narrative coherence, and usability rather than purely technical features. In MR exhibitions, this implies that well-designed narratives and intuitive interactions can deliver impactful experiences without excessive resource use.

Minimalist design approaches emerge as a viable strategy for balancing experiential quality and sustainability. By focusing on essential elements and reducing unnecessary complexity, designers can create engaging experiences while minimising computational demands. For example, the use of stylised graphics instead of photorealistic rendering can reduce processing requirements while maintaining aesthetic appeal.

Furthermore, the concept of “meaningful engagement” plays a crucial role in sustainable experience design. Experiences that resonate with users on an emotional or intellectual level are more likely to have a lasting impact, reducing the need for repeated or prolonged interactions. This, in turn, can contribute to lower energy consumption and more efficient use of resources.

5.3 Technological Adaptability and Longevity

Technological obsolescence is identified as a major barrier to sustainability in MR exhibitions. The rapid evolution of hardware and software platforms results in frequent updates and replacements, increasing resource consumption and environmental impact. This issue is particularly pronounced in MR systems, where compatibility and interoperability are often limited.

The findings emphasise the importance of designing for adaptability and longevity. Scalable and modular systems allow for incremental upgrades, reducing the need for complete system replacement. For instance, software updates can extend the functionality of existing hardware, while modular components enable targeted improvements without discarding entire systems (McDonough & Braungart, 2002).

Cross-platform compatibility is another critical factor in enhancing sustainability. By designing MR applications that can operate across different devices and platforms, designers can reduce dependency on specific hardware and extend the usability of digital content. This approach aligns with the principles of circular design, which emphasise reuse and resource efficiency.

Cloud-based solutions also offer potential benefits in terms of scalability and resource optimisation. By centralising computational processes, cloud computing can reduce the need for high-performance local hardware. However, this approach must be balanced against the energy demands of data centres, which contribute significantly to global energy consumption (Hilty et al., 2006).

5.4 Socio-Cultural Sustainability and Inclusivity

Sustainable MR exhibition design must also address socio-cultural dimensions, including accessibility, inclusivity, and ethical considerations. The findings indicate that many MR exhibitions are designed for technologically literate audiences, potentially excluding individuals with limited access to digital technologies or those with disabilities.

Human-centred design principles are essential for addressing these challenges. Norman (2013) emphasises the importance of designing systems that accommodate diverse user needs and capabilities. In MR exhibitions, this includes providing alternative interaction methods, such as gesture-based or voice-controlled interfaces, and ensuring compatibility with assistive technologies.

Cultural sustainability is another important consideration. MR exhibitions often involve the representation of cultural heritage and narratives, requiring sensitivity to cultural contexts and values. Designers must ensure that digital content is accurate, respectful, and inclusive, avoiding misrepresentation or cultural appropriation.

Ethical considerations also extend to data privacy and user well-being. MR systems often collect and process user data, raising concerns about privacy and security. Additionally, immersive experiences can have psychological effects, such as motion sickness or cognitive overload, which must be addressed through careful design (Hassenzahl, 2010).

5.5 Case Study Insights and Best Practices

The analysis of documented MR exhibition case studies reveals several best practices for sustainable design. One notable trend is the use of augmented reality (AR) as an alternative to fully immersive VR systems. AR applications, which overlay digital content onto physical environments, typically require less specialised hardware and can be accessed through widely available devices

such as smartphones and tablets (Tom Dieck & Jung, 2017). This approach reduces both hardware dependency and energy consumption.

Another best practice is the integration of physical and digital elements. Hybrid exhibitions that combine traditional displays with MR components can reduce reliance on digital systems while enhancing user engagement. For example, physical artefacts can serve as anchors for digital content, creating a balanced and resource-efficient experience.

The reuse and adaptation of digital assets also contribute to sustainability. Digital content can be repurposed across multiple exhibitions or platforms, reducing the need for new resources. This approach aligns with circular design principles and promotes long-term efficiency.

Overall, the findings highlight the need for a holistic approach to sustainable MR exhibition design. The four key dimensions—ecological, experiential, technological, and socio-cultural—are deeply interconnected and must be considered simultaneously. The analysis demonstrates that sustainability is not a constraint but an opportunity to enhance design quality and innovation.

6. Discussion

The findings of this study underscore the complexity of integrating sustainability into Mixed Reality (MR) exhibition design. This discussion critically interprets the results in relation to the theoretical framework and existing literature, highlighting key

implications for design practice, theory development, and future research.

6.1 Reconciling Experience Economy and Sustainability

One of the central tensions identified in this study is the apparent conflict between the principles of the experience economy and the goals of sustainability. Pine and Gilmore (1999) emphasise the creation of immersive and memorable experiences as a source of economic value. In MR exhibitions, this often translates into the use of advanced technologies and high levels of sensory engagement.

However, the findings suggest that this tension can be reconciled through a redefinition of experiential value. Rather than equating immersion with technological intensity, designers can focus on creating meaningful and emotionally resonant experiences. Hassenzahl (2010) argues that user experience is shaped by psychological needs, such as autonomy, competence, and relatedness, rather than purely technical features.

This perspective aligns with sustainable design principles, which emphasise efficiency and simplicity. By prioritising meaningful engagement over technological excess, MR exhibitions can achieve both experiential quality and sustainability. This shift represents a move toward what can be described as “sustainable experience economy,” where value is created through responsible and thoughtful design.

6.2 Toward a Circular Model of MR Design

The findings highlight the importance of adopting a circular approach to MR exhibition design. Traditional linear models of production and consumption, characterised by “take, make, dispose”, are incompatible with sustainability goals (McDonough & Braungart, 2002). In contrast, circular design emphasises reuse, recycling, and regeneration.

In MR contexts, circularity can be achieved through several strategies. First, modular design enables components to be upgraded or replaced without discarding entire systems. Second, digital assets can be reused and adapted across different contexts, reducing the need for new resources. Third, cross-platform compatibility extends the lifespan of software and content.

These strategies not only reduce environmental impact but also enhance economic efficiency by lowering costs associated with hardware replacement and content development. However, implementing circular design requires systemic changes, including collaboration between designers, manufacturers, and policymakers.

6.3 Human-Centred Sustainability

The integration of human-centred design (HCD) into sustainability frameworks represents a significant advancement in MR exhibition design. Traditional sustainability approaches often focus on environmental metrics, overlooking the role of user experience and behaviour. This study demonstrates that HCD can bridge this gap

by aligning sustainability with user needs and preferences.

Norman (2013) emphasises that successful design must be intuitive, accessible, and meaningful. In MR exhibitions, this involves creating experiences that are inclusive and adaptable to diverse audiences. For example, providing multiple modes of interaction can accommodate users with different abilities and technological familiarity.

Moreover, HCD contributes to sustainability by influencing user behaviour. Engaging and meaningful experiences can promote awareness of environmental issues and encourage sustainable practices. For instance, MR exhibitions can simulate the impacts of climate change, fostering empathy and understanding among users.

6.4 Technological Innovation and Ethical Responsibility

The rapid evolution of MR technologies presents both opportunities and challenges for sustainable design. On one hand, technological innovation enables more efficient and scalable systems. On the other hand, it contributes to obsolescence and increased resource consumption.

The findings suggest that ethical responsibility must be a central consideration in MR design. This includes addressing issues such as data privacy, accessibility, and user well-being. Designers must ensure that MR technologies are used in ways that benefit users and society, rather than simply pursuing technological advancement for its own sake.

Ethical design also involves transparency and accountability. Users should be informed about how their data is collected and used, and systems should be designed to protect user privacy. Additionally, designers must consider the potential psychological and physiological effects of immersive experiences, ensuring that they are safe and comfortable for users.

6.5 Implications for Practice

The proposed framework has several practical implications for designers and practitioners:

- **Holistic design approach:** Consider ecological, experiential, technological, and socio-cultural dimensions simultaneously
- **Lifecycle thinking:** Design systems for long-term use and adaptability
- **User-centred sustainability:** Align sustainability goals with user needs and experiences
- **Collaborative design:** Engage stakeholders from multiple disciplines

These principles can guide the development of MR exhibitions that are both innovative and sustainable.

6.6 Implications for Future Research

This study highlights several areas for future research. First, empirical studies are needed to validate the proposed framework and assess its effectiveness in real-world contexts. Second, research should explore the role of emerging technologies, such as artificial intelligence and edge computing, in

enhancing sustainability. Third, interdisciplinary approaches are needed to address the complex challenges of MR design.

In conclusion, the integration of sustainability into MR exhibition design represents a critical challenge and opportunity. By reconciling experiential and ecological goals, adopting circular design principles, and prioritising human-centred approaches, designers can create MR experiences that are both engaging and responsible. This study contributes to this endeavour by providing a comprehensive framework for sustainable MR exhibition design.

7. Conclusion

This study has explored the complex relationship between sustainability and experience design within the context of Mixed Reality (MR) exhibitions. By synthesising insights from existing literature, theoretical frameworks, and documented case studies, the research has demonstrated that sustainable MR exhibition design is not only feasible but also essential in the contemporary digital landscape. As immersive technologies continue to evolve, the need to balance innovation with environmental and social responsibility becomes increasingly critical.

One of the key contributions of this study is the development of an integrated framework that brings together ecological, experiential, technological, and socio-cultural dimensions of MR design. This framework highlights that sustainability should not be treated as a

secondary consideration but as a core design principle that informs all stages of the exhibition lifecycle. The findings emphasise that high-quality user experiences do not necessarily require resource-intensive technologies; rather, they can be achieved through thoughtful design, narrative coherence, and user-centred approaches.

The research also underscores the importance of lifecycle thinking and circular design in addressing the environmental challenges associated with MR systems. By adopting modular architectures, cross-platform compatibility, and reusable digital assets, designers can extend the lifespan of MR technologies and reduce their ecological footprint. Furthermore, the integration of human-centred design principles ensures that MR exhibitions are accessible, inclusive, and ethically responsible, thereby contributing to broader socio-cultural sustainability.

From a practical perspective, the proposed case study framework provides actionable guidance for designers, curators, and policymakers. It encourages a holistic approach that considers not only technological capabilities but also environmental impact, user well-being, and cultural relevance. This interdisciplinary perspective is essential for navigating the complexities of MR design and achieving sustainable outcomes.

Despite its contributions, the study is limited by its reliance on secondary data, which may not fully capture the nuances of user experiences and real-world implementation. Future research should focus on empirical validation of the proposed framework through case-based investigations, user

studies, and experimental methodologies. Additionally, emerging technologies such as artificial intelligence, edge computing, and low-energy systems offer promising avenues for enhancing sustainability in MR environments.

In conclusion, sustainable experience design in MR exhibitions represents a critical frontier in both design research and practice. By aligning immersive innovation with ecological responsibility and human-centred values, designers can create meaningful and enduring experiences that contribute positively to both society and the environment.

References

- Belkhir, L., & Elmeligi, A. (2018). Assessing ICT global emissions footprint: Trends to 2040 and recommendations. *Journal of Cleaner Production*, 177, 448–463. <https://doi.org/10.1016/j.jclepro.2017.12.239>
- Billinghurst, M., Clark, A., & Lee, G. (2015). A survey of augmented reality. *Foundations and Trends in Human-Computer Interaction*, 8(2–3), 73–272. <https://doi.org/10.1561/11000000049>
- Bhamra, T., & Lofthouse, V. (2016). *Design for sustainability: A practical approach*. Routledge.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.
- <https://doi.org/10.1191/1478088706qp063oa>
- Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). Sage.
- Damala, A., Marchal, I., & Houlier, P. (2019). Merging augmented reality-based features in mobile multimedia museum guides. *Museum Management and Curatorship*, 34(2), 1–20.
- Hassenzahl, M. (2010). *Experience design: Technology for all the right reasons*. Morgan & Claypool.
- Hilty, L. M., & Aebischer, B. (2015). *ICT for sustainability: An emerging research field*. Springer.
- Hilty, L. M., Arnfalk, P., Erdmann, L., Goodman, J., Lehmann, M., & Wäger, P. A. (2006). The relevance of information and communication technologies for environmental sustainability. *Environmental Modelling & Software*, 21(11), 1618–1629.
- Johnston, M. P. (2017). Secondary data analysis: A method whose time has come. *Qualitative and Quantitative Methods in Libraries*, 3(3), 619–626.
- Mannan, K.A., & Farhana, K.M. (2026). *The Principles of Qur'anic Research Methodology: Deriving the Process of Knowledge from Revelation*. KMF Publishers. Open Access (CC BY 4.0). DOI:

<https://doi.org/10.64907/xkmf.book.pqrm.26.02.12>

- McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things*. North Point Press.
- Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information Systems*, E77-D(12), 1321–1329.
- Norman, D. A. (2013). *The design of everyday things* (Revised and expanded ed.). Basic Books.
- Pine, B. J., & Gilmore, J. H. (1999). *The experience economy: Work is theatre and every business a stage*. Harvard Business School Press.
- Sylaiou, S., Mania, K., Karoulis, A., & White, M. (2010). Exploring the relationship between presence and enjoyment in a virtual museum. *Journal of Cultural Heritage*, 11(4), 520–528.
- Tom Dieck, M. C., & Jung, T. (2017). Value of augmented reality at cultural heritage sites: A stakeholder approach. *Journal of Destination Marketing & Management*, 6(2), 110–117.
- Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.