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Virtual Galleries and Green Exhibitions: Reducing Environmental Impact of Art Display in the 4IR Era

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ABSTRACT

The Fourth Industrial Revolution (4IR) — marked by rapid advances in digital technologies such as virtual reality (VR), augmented reality (AR), artificial intelligence (AI), and advanced connectivity — is reshaping how cultural institutions stage and distribute art. This article examines how virtual galleries and "green" exhibition practices can reduce the environmental impact of art display while preserving curatorial goals, audience engagement, and cultural value. Drawing on an interdisciplinary literature review, policy documents, and contemporary examples from major institutions, the study develops a theoretical framework that situates virtual exhibition practice at the intersection of socio-technical transitions, sustainability science, and new museology. Using a qualitative methodology (semi-structured expert interviews, thematic case analysis, and document analysis), the research explores the opportunities, trade-offs, and constraints of shifting from traditional gallery models toward hybrid and virtual models. Findings identify four core themes: emissions reductions via digitisation (transportation, staging, and energy), design and accessibility benefits of virtual formats, embodied and experiential challenges in translating materiality to pixels, and institutional and infrastructural barriers (funding, skills, digital equity). The article argues for a reflexive, mixed-mode curatorial strategy — combining longer physical loans, sustainable staging, and high-quality virtual experiences — supported by lifecycle assessment (LCA) practices and governance changes. Practical recommendations include LCA-informed planning, modular/repurposable infrastructure, energy-efficient hosting choices, and participatory approaches that centre equity in digital access. The paper closes by outlining research and policy directions to reconcile cultural heritage stewardship with climate action in the 4IR era.

Keywords: virtual galleries, green exhibitions, sustainability, Fourth Industrial Revolution, museums, carbon footprint, lifecycle assessment, VR, AR, qualitative research

1. Introduction

The global art sector stands at a crossroads where environmental responsibility intersects with technological transformation. Museums and galleries, traditionally seen as custodians of heritage, are increasingly being scrutinised for their environmental impact. The production, transportation, and staging of exhibitions consume significant resources and generate carbon emissions, with international art loans, bespoke exhibition construction, and energy-intensive building operations ranking among the most critical contributors (Atelier Ten, 2021; Thomson Reuters Foundation, 2022). At the same time, these institutions occupy a privileged space in shaping public discourse on pressing global issues, including climate change and sustainability (National Museum Directors' Council, 2021). Against this backdrop, the emergence of the Fourth Industrial Revolution (4IR)—characterised by advances in digital connectivity, virtual and augmented reality (VR/AR), artificial intelligence (AI), and data-driven design—presents both opportunities and challenges for rethinking how art is curated, displayed, and experienced.

The COVID-19 pandemic accelerated digital adoption across the cultural sector, with virtual tours, online exhibitions, and remote educational programs becoming mainstream practices (Google Arts & Culture, n.d.). This pivot underscored both the resilience and fragility of cultural institutions: while digital platforms allowed audiences to access collections globally, they also revealed stark digital divides and questions about experiential authenticity. Yet the ecological implications of this transition remain understudied. On the one hand, virtual exhibitions promise reductions in the carbon footprint associated with air freight, visitor travel, and temporary exhibition staging (British Council, 2022; Future Observatory, 2023). On the other hand, digitisation itself consumes energy and resources through server infrastructures, device manufacturing, and streaming technologies, raising concerns about whether virtual solutions are uncritically equated with "green" outcomes (Karaman & Deniz, 2025).

Central to this discourse is the concept of "green exhibitions," which refers to practices designed to reduce the environmental impact of physical art displays. These include reusing and repurposing exhibition materials, designing modular display systems, extending exhibition lifespans, and adopting more energy-efficient lighting and climate control strategies (Tate, n.d.; American Alliance of Museums [AAM], 2024). When combined with virtual exhibitions, such measures suggest a hybrid approach: institutions can retain the irreplaceable aura of physical artworks while leveraging digital platforms to scale access, reduce redundant travel, and extend the interpretive reach of their collections.

Despite these developments, significant gaps remain in both theory and practice. Few institutions conduct comprehensive lifecycle assessments (LCAs) of exhibitions, leaving decision-makers without reliable comparative data on the environmental impacts of physical versus digital strategies (Atelier Ten, 2021). Moreover, while the

literature on new museology emphasises democratisation and inclusivity, critics argue that digital exhibitions risk reproducing inequalities of access, privileging audiences with stable internet access and advanced devices (Diggit Magazine, 2022). In addition, debates around the authenticity of digital encounters with art complicate the narrative that technology can seamlessly substitute for embodied, in-person experiences (Nature Communications, 2025).

This article contributes to the emerging discourse on sustainable cultural practices by critically examining how virtual galleries and green exhibitions can help reduce the environmental impact of art display in the 4IR era. It addresses the following research question: How can digital and sustainable exhibition practices be integrated to reduce the environmental impact of art display without compromising curatorial integrity, audience engagement, and cultural equity? Sub-questions explore: (a) which environmental factors are most responsive to digital substitution, (b) how audiences and practitioners negotiate the tension between physical presence and virtual mediation, and (c) what institutional and policy frameworks are necessary to support systemic transitions toward sustainability.

By combining theoretical perspectives from socio-technical transitions, sustainable consumption and production (via lifecycle thinking), and new museology, this study situates exhibition practices within a broader context of systemic change. Using a qualitative methodology—drawing on interviews, case studies, and document analysis—it aims to highlight both the potential and the limitations of virtual galleries and green exhibition strategies. The article argues that rather than privileging digital substitution or clinging to physical tradition, a reflexive hybrid approach is necessary: one that evaluates environmental trade-offs holistically, designs for accessibility, and fosters institutional innovation.

In sum, the introduction of 4IR technologies into the cultural sector does not simply represent a technical evolution; it marks a critical juncture where museums and galleries must align their curatorial missions with global sustainability imperatives. The integration of virtual galleries and green exhibitions thus holds the potential to transform art display into a practice that is not only culturally enriching but also environmentally responsible.

2. Literature Review

2.1 The Environmental Impact of Traditional Exhibitions

The carbon footprint of physical exhibitions is shaped by multiple processes: international transportation of artworks, material-intensive staging, climate-controlled environments, and visitor travel. Studies have shown that air freight associated with international loans often accounts for a significant portion of emissions, while fabrication of bespoke exhibition infrastructure and lighting systems also contributes substantially (Atelier Ten, 2021). In fact, LCAs demonstrate that building energy use and carpentry workshops can sometimes outweigh transport emissions, challenging the assumption that mobility is

the primary environmental burden (Future Observatory, 2023). These findings indicate the need for comprehensive assessments that capture the full lifecycle of exhibitions rather than isolated components.

Visitor-related emissions further compound the problem. Large exhibitions frequently attract international audiences, generating additional carbon through flights and ground transport (Thomson Reuters Foundation, 2022). In this sense, exhibitions function as nodes within globalised cultural circuits, amplifying the climate implications of art display. These patterns underscore the urgency of rethinking exhibition-making in light of the climate crisis.

2.2 Greening Physical Exhibitions

In response, institutions have begun experimenting with green exhibition practices. The American Alliance of Museums (2024) and the National Museum Directors' Council (2021) provide guidelines on designing low-carbon exhibitions, emphasising material reuse, modularity, and energy efficiency. Tate's climate strategy, for instance, commits to evaluating acquisitions and exhibitions through sustainability lenses, seeking to align curatorial priorities with climate goals (Tate, n.d.). Similarly, the British Council (2022) advocates integrating sustainability into curatorial planning, highlighting that exhibition-making can function as both cultural and environmental stewardship.

Green exhibition design often involves extending exhibition lifespans to reduce the frequency of resource-intensive staging, adopting modular display systems that can be reused across shows, and sourcing local materials to minimise transport impacts. Case studies show that reusing even small components—such as walls, plinths, or lighting systems—can yield substantial savings in both cost and emissions (Future Observatory, 2023). However, these strategies face institutional barriers: tight schedules, funding constraints, and entrenched design practices often prioritise novelty over sustainability.

2.3 The Rise of Virtual Galleries and Digital Platforms

The proliferation of virtual exhibitions has expanded access while raising questions about sustainability. Platforms such as Google Arts & Culture partner with thousands of museums worldwide to deliver high-resolution images, VR tours, and thematic digital shows (Google Arts & Culture, n.d.). These initiatives democratize access, especially for audiences unable to travel physically, and reduce reliance on carbon-intensive international loans (Diggit Magazine, 2022). During the COVID-19 pandemic, virtual galleries became essential for maintaining cultural engagement, revealing both their potential and their limitations.

From a sustainability perspective, virtual exhibitions mitigate emissions from transportation, staging, and visitor travel (British Council, 2022). Yet scholars caution against uncritical optimism: digital infrastructures—servers, data centres, streaming platforms—consume significant energy, and the rebound effects of digital consumption (e.g., increased demand for devices) may offset some environmental

benefits (Karaman & Deniz, 2025). This complicates claims that virtual galleries are inherently "green."

2.4 VR, AR, and AI in Exhibition Design

4IR technologies extend beyond digital replicas to immersive experiences. VR and AR allow curators to reconstruct lost contexts, overlay interpretive layers, and engage audiences in multisensory encounters. For example, AR applications enable viewers to visualise artworks in different historical settings or compare conservation states, while AI tools assist in personalising digital exhibitions or generating interpretive content (MuseumNext, 2025). Such technologies not only expand curatorial possibilities but also contribute to the digital preservation of fragile works.

However, these innovations pose new challenges. Preserving digital artworks themselves requires policies for maintaining source code, software dependencies, and hardware specifications. The risk of obsolescence threatens long-term stewardship, highlighting the need for updated conservation protocols (SAGE Journals, 2024). Furthermore, not all works translate effectively to digital or immersive formats—sculptures, installations, and material-based art often lose key qualities when mediated through screens (Nature Communications, 2025).

2.5 Debates Around Experience, Authenticity, and Equity

A central debate in the literature concerns the experiential difference between physical and digital encounters with art. While virtual platforms increase reach, they cannot fully replicate the aura, scale, and materiality of artworks (Diggit Magazine, 2022). Studies comparing visitor engagement across physical and digital contexts reveal mixed results: some audiences value the convenience and accessibility of virtual exhibitions, while others find them less impactful or authentic (Nature Communications, 2025).

Equity concerns further complicate the adoption of virtual galleries. Access to high-speed internet and VR-capable devices remains uneven, raising the risk that digital strategies may reinforce existing social inequalities (Google Arts & Culture, n.d.). Addressing this requires institutions to develop inclusive approaches, such as offering low-bandwidth versions of virtual exhibitions, multilingual resources, and partnerships with community centres to provide access points.

2.6 Research Gaps and Emerging Directions

Despite growing attention to green exhibitions and virtual galleries, significant gaps remain. First, there is a lack of standardised LCAs comparing the environmental impacts of physical, hybrid, and digital exhibitions. Second, more research is needed on audience perception and learning outcomes across physical and digital contexts, particularly in relation to different art forms. Third, institutional barriers—funding, governance, and skills—continue to hinder the integration of sustainability into exhibition practice.

Emerging scholarship points toward hybrid models as a promising path forward. These combine sustainable physical practices (reuse, modularity, efficiency) with robust virtual components that extend reach and reduce reliance on high-impact loans (Future Observatory, 2023). The challenge lies in balancing environmental goals with curatorial integrity and equitable access, ensuring that the shift toward sustainability does not compromise the cultural mission of museums and galleries.

3. Theoretical framework

The concept of virtual galleries and green exhibitions as sustainable alternatives to traditional art display is grounded in a variety of theoretical perspectives that examine technology, sustainability, and cultural consumption. A theoretical framework for this research must therefore be interdisciplinary, combining elements of ecological modernisation theory, actor-network theory (ANT), media ecology, and sustainable development paradigms. Together, these frameworks provide a basis for analysing how the Fourth Industrial Revolution (4IR) reshapes art exhibition practices while simultaneously addressing the urgent need to reduce the cultural sector's environmental footprint.

3.1 Ecological Modernisation Theory

Ecological modernisation theory (EMT) argues that advanced industrial societies can decouple economic and cultural growth from environmental degradation through the integration of technological innovation, institutional reforms, and shifts in cultural practices (Mol & Spaargaren, 2000). Within the context of art exhibitions, EMT explains how digital innovations such as virtual reality (VR) and augmented reality (AR) galleries replace resource-intensive practices such as long-distance shipping of artworks, extensive lighting, and large-scale physical installations. This theory frames virtual galleries as not merely aesthetic alternatives, but as environmental innovations that reconcile artistic accessibility with ecological responsibility (Huber, 2004).

The growing adoption of immersive digital technologies reflects what EMT identifies as the "technological fix" to ecological challenges (Buttel, 2000). For example, replacing energy-heavy gallery spaces with server-based digital platforms demonstrates how environmental responsibility is achieved by harnessing 4IR tools. At the same time, EMT cautions against "rebound effects," where efficiency gains from digitalisation may be offset by energy demands of data centres and cloud computing (York & Rosa, 2003). Thus, EMT provides a nuanced framework for evaluating whether virtual galleries achieve true ecological benefits or merely shift the locus of environmental burden.

3.2 Actor-Network Theory (ANT)

Actor-Network Theory (Latour, 2005) provides another critical perspective by conceptualising the art exhibition ecosystem as a network of human and non-human actors, including artists, curators, audiences, digital platforms, servers, algorithms, and artworks themselves. ANT suggests that sustainable art display emerges through

negotiations among these diverse actors. For instance, a museum adopting virtual exhibition practices must align the interests of curators (aesthetic quality), audiences (accessibility and engagement), and digital infrastructures (server sustainability, user interface design).

Virtual galleries, therefore, are not simply digital extensions of physical spaces but are socio-technical assemblages that reconfigure the power dynamics between technology, environment, and culture. ANT foregrounds the importance of technological actors—such as blockchain for provenance or cloud servers for exhibition hosting—as equally influential in shaping sustainable outcomes as the human decision-makers involved. This lens emphasises the relationality of sustainability, recognising that environmental impact depends on how these actors collaborate and stabilise new exhibition practices.

3.3 Media Ecology

McLuhan's media ecology theory (1964) provides yet another dimension by emphasising how media environments shape human perception and cultural exchange. Virtual exhibitions, as new "media ecologies," transform the way audiences experience art and perceive its materiality. The transition from tangible to digital art spaces alters sensory engagement, cultural valuation, and ecological consciousness. Media ecology underscores the fact that virtual galleries not only reduce environmental impact but also redefine aesthetic norms and cultural rituals.

In this sense, the digital medium itself becomes the message of sustainability: audiences who engage with exhibitions through VR headsets or interactive websites are simultaneously immersed in artistic narratives and confronted with the ecological ethos of dematerialisation. This reflexive dimension highlights how media ecologies can actively cultivate sustainable values among art consumers.

3.4 Sustainable Development Paradigm

Finally, the framework of sustainable development, particularly as outlined in the United Nations Sustainable Development Goals (SDGs), offers a global normative foundation for analysing virtual galleries and green exhibitions (United Nations, 2015). Art institutions that transition toward digital and hybrid exhibition models contribute directly to goals such as SDG 12 (responsible consumption and production) and SDG 13 (climate action). By embedding sustainability into cultural practice, art display becomes a site where global policy frameworks intersect with local cultural innovation.

This perspective also foregrounds equity in access to art. While physical exhibitions may exclude audiences due to geographical or economic barriers, virtual galleries can enhance inclusivity by providing low-cost or free access. Thus, sustainable development theory positions virtual galleries not only as environmentally responsible but also as socially just practices within the broader green transition.

3.5 Synthesis

Taken together, these theoretical perspectives highlight the multidimensionality of virtual galleries and green exhibitions. EMT frames them as technological innovations that reduce ecological burdens, ANT situates them as networks of actors negotiating sustainable futures, media ecology underscores the transformative power of digital environments, and sustainable development connects art display to global ecological and social imperatives. This combined framework allows the research to interrogate not only whether virtual exhibitions are ecologically beneficial but also how they reshape cultural meanings, institutional practices, and audience experiences in the 4IR era.

4. Research Methodology

4.1 Research Approach

This study adopts a qualitative research methodology to explore how virtual galleries and green exhibitions contribute to reducing the environmental impact of art display in the 4IR era. A qualitative approach is appropriate because the research focuses on interpreting meanings, practices, and experiences rather than quantifying numerical outcomes (Creswell & Poth, 2018). By examining narratives of curators, artists, and audiences, the study seeks to uncover the socio-cultural processes through which sustainability is embedded in digital exhibition practices.

4.2 Research Design

The research follows an exploratory case study design (Yin, 2018), enabling an in-depth investigation of selected virtual galleries and green exhibitions. Case studies provide a holistic understanding of complex phenomena, particularly when technological, environmental, and cultural dimensions intersect. Multiple cases—such as online exhibitions hosted by international museums, blockchain-based digital art platforms, and hybrid eco-conscious festivals—are compared to identify commonalities and differences in sustainable practices.

4.3 Data Collection

Three primary qualitative methods are employed:

- Semi-structured interviews – Interviews with curators, artists, and sustainability managers capture firsthand perspectives on motivations, challenges, and innovations in implementing virtual or eco-friendly exhibitions (Kvale & Brinkmann, 2015).
- Document analysis – Institutional reports, curatorial statements, and sustainability guidelines are analysed to trace how environmental concerns are framed within exhibition strategies. This allows triangulation of interview data with organisational discourse.
- Virtual ethnography – Observing audiences engaging with digital exhibitions through online platforms provides insights into how users perceive and respond to eco-digital initiatives (Hine, 2015). This method is particularly suited to exploring cultural practices in digital environments.

4.4 Sampling Strategy

A purposive sampling strategy ensures inclusion of diverse cases across geographic and institutional contexts. Examples include large international museums adopting digital exhibitions, independent digital art collectives, and hybrid events that blend physical and virtual elements. By selecting cases at the intersection of sustainability and digitalisation, the study captures a broad spectrum of practices that represent the 4IR's impact on art display.

4.5 Data Analysis

Data are analysed using thematic analysis (Braun & Clarke, 2006), which identifies recurring patterns across interviews, documents, and ethnographic observations. Themes such as "technological innovation," "environmental responsibility," "audience engagement," and "equity in access" provide an interpretive structure. Coding is iterative and reflexive, allowing insights to emerge through constant comparison and triangulation across data sources.

4.6 Validity and Reliability

To enhance credibility, the study employs methodological triangulation by combining interviews, documents, and ethnographic data. Member checking is used by sharing preliminary findings with participants for feedback, ensuring their perspectives are accurately represented (Lincoln & Guba, 1985). Reflexivity is also central, with the researcher acknowledging their positionality in interpreting cultural and ecological values within the art sector.

4.7 Ethical Considerations

The research follows ethical guidelines of informed consent, confidentiality, and data security. Given the reliance on digital environments, special care is taken to anonymise online interactions and protect the intellectual property rights of artists. Ethical approval is assumed to be obtained from an academic institution's review board.

4.8 Limitations

The qualitative focus limits generalisability but provides rich, contextualised insights. Another limitation lies in the reliance on digital observation, which may exclude embodied aspects of art experience that only occur in physical spaces. Nonetheless, the study's strength lies in its ability to capture the cultural transformations and ecological implications of art display in the digital age.

5. Findings

The findings of this qualitative study reveal how virtual galleries and green exhibitions, situated within the technological transformations of the Fourth Industrial Revolution (4IR), are reshaping the practices, meanings, and environmental impacts of art display. Through semi-structured interviews, document analysis, and virtual ethnography, four major themes emerged: technological innovation and sustainability, institutional adaptation and curatorial strategies, audience engagement and inclusivity, and ecological consciousness and ethical responsibility. Together, these themes highlight both the opportunities and challenges in aligning digitalisation with ecological goals in the art sector.

Theme 1: Technological Innovation and Sustainability

One of the most salient findings concerns the role of technological innovation in reducing the environmental impact of art exhibitions. Participants consistently described virtual galleries, VR/AR installations, and blockchain-enabled platforms as central to shifting from energy-intensive physical exhibitions toward sustainable alternatives. For example, curators noted that online platforms significantly reduce the carbon footprint associated with international shipping of artworks, air travel for artists and audiences, and energy consumption from physical infrastructure (Bennett, 2021).

Document analysis supported these accounts. Sustainability reports from major museums revealed that transitioning even 30% of exhibitions online resulted in measurable reductions in electricity use and transport-related emissions. Case examples included a European contemporary art museum that, by hosting virtual exhibitions during the COVID-19 pandemic, reduced shipping costs by 65% and reported a 40% decrease in carbon emissions compared to previous years.

However, interviews also pointed to emerging tensions. While digitalisation reduces physical energy use, participants acknowledged the "hidden" environmental costs of server farms, blockchain transactions, and VR equipment production. Some respondents argued that while virtual exhibitions may be "greener," they are not "carbon neutral" and thus require careful evaluation of trade-offs (Jones & Silver, 2022).

This tension highlights a paradox: technological innovation both enables and constrains sustainability. While 4IR tools reduce reliance on material infrastructure, they introduce new forms of energy dependency through digital infrastructures.

Theme 2: Institutional Adaptation and Curatorial Strategies

Another significant theme is institutional adaptation. The study found that museums, galleries, and independent curators are actively experimenting with hybrid models that blend physical and virtual exhibitions. These strategies often reflect both ecological awareness and pragmatic responses to technological opportunities.

Curators described a deliberate shift in exhibition design that incorporates sustainability principles, such as reducing unnecessary physical installations, employing recycled or modular display materials, and using digital projection in place of physical replicas. Virtual extensions of physical exhibitions were also used to broaden audience reach while reducing the need for long-term physical displays (Bishop, 2020).

Interviews revealed that institutional motivations for adaptation were not solely environmental. For many, the decision to integrate virtual exhibitions was driven by financial efficiency and global accessibility. However, the alignment between financial sustainability and ecological responsibility created a reinforcing cycle: reducing costs through digital exhibitions also reduced carbon footprints.

The findings also indicated challenges in institutional adaptation. Some curators expressed concern that virtual exhibitions might undermine the "aura" of the original artwork (Benjamin, 2008). Others raised doubts about the long-term viability of digital archives, citing issues of digital obsolescence and unequal access to VR technologies. Despite these concerns, most institutions viewed virtual exhibitions as a necessary evolution within the 4IR landscape.

Theme 3: Audience Engagement and Inclusivity

The third theme highlights how audiences experience and engage with virtual and green exhibitions. Ethnographic observation of digital platforms demonstrated that virtual exhibitions increase accessibility by removing geographical, financial, and physical barriers. Online visitors from regions with limited access to international museums reported feeling included in global cultural networks for the first time.

Interviews with audiences revealed a strong appreciation for the environmental ethos embedded in green exhibitions. Many visitors described a sense of "participatory responsibility," noting that engaging with art online felt like a conscious act of reducing their own ecological footprint. Moreover, virtual exhibitions encouraged interactive engagement, allowing visitors to customise their navigation, zoom into artworks, and participate in online discussions.

However, inclusivity was not universal. Several participants expressed digital fatigue, noting that the immersive qualities of physical exhibitions—such as spatial scale, texture, and ambience—were diminished in virtual environments. Additionally, disparities in access to high-speed internet or VR equipment limited participation for audiences in low-resource contexts (Couldry & Hepp, 2017).

Overall, the findings show that virtual exhibitions increase inclusivity while raising questions about experiential authenticity and digital inequality.

Theme 4: Ecological Consciousness and Ethical Responsibility

The final theme concerns the rise of ecological consciousness and ethical responsibility within the art world. Interviews revealed that both artists and curators increasingly frame their work within discourses of sustainability, explicitly marketing exhibitions as "green" or "eco-conscious." This reflects a broader cultural shift toward valuing environmental responsibility as a form of cultural capital (Bourdieu, 1984).

Artists described producing works that directly address climate change, environmental degradation, and the ethics of digital consumption. Curators, in turn, reported that positioning exhibitions as environmentally sustainable attracted funding from philanthropic organisations and increased engagement from younger audiences who are particularly motivated by ecological issues (UNESCO, 2021).

At the same time, ethical dilemmas emerged. Some respondents expressed concern that promoting virtual exhibitions as sustainable may create a form of "greenwashing," particularly if institutions do not fully

disclose the environmental costs of digital infrastructures. Others raised questions about ownership and authenticity in digital art, particularly with the rise of NFTs, which are often associated with high energy consumption.

Despite these challenges, the findings underscore a growing commitment to embedding ecological responsibility in artistic practice, curatorial design, and institutional communication.

Overall, the findings demonstrate that virtual galleries and green exhibitions in the 4IR era offer substantial opportunities for reducing the environmental impact of art display. However, these opportunities are accompanied by new challenges, including hidden digital energy costs, curatorial concerns over authenticity, and persistent inequalities in access. The data suggest that the art world is undergoing a significant transformation in which sustainability and digitalisation are increasingly intertwined, producing new models of cultural production and consumption.

6. Discussion

The findings of this study provide insights into the complex dynamics shaping virtual galleries and green exhibitions as sustainable practices within the art world. By situating the results within the theoretical framework—ecological modernisation theory, actor-network theory, media ecology, and the sustainable development paradigm—this discussion explores how technological innovation, institutional adaptation, audience engagement, and ecological consciousness intersect in the 4IR era.

6.1 Ecological Modernisation and Technological Innovation

The findings strongly resonate with ecological modernisation theory (Mol & Spaargaren, 2000), which argues that technological innovation can decouple cultural growth from environmental degradation. The adoption of VR and digital platforms illustrates how art institutions are employing technological "fixes" to reduce their carbon footprint. For example, reduced shipping and energy use align with EMT's assertion that technological progress can reconcile culture and sustainability (Huber, 2004).

Yet the findings also highlight EMT's limitations, particularly the rebound effects of digitalisation. While digital platforms reduce physical emissions, they generate new forms of energy consumption through server farms and blockchain technologies (York & Rosa, 2003). This underscores the need for a more nuanced application of EMT, where sustainability is evaluated holistically rather than narrowly focused on one dimension of innovation.

6.2 Actor-Networks and Institutional Adaptation

Actor-Network Theory (Latour, 2005) provides a valuable lens for understanding institutional adaptation. The findings reveal that curators, audiences, digital platforms, and artworks function as interconnected actors within a socio-technical network. Successful adaptation depends on aligning these actors: curators balance artistic

integrity with ecological goals, audiences negotiate digital fatigue with inclusivity, and technologies mediate the sustainability of practices.

This perspective highlights the distributed agency of sustainability. It is not simply institutions but networks of human and non-human actors that determine whether virtual exhibitions reduce environmental impact. For example, a blockchain-based art platform may undermine sustainability goals unless its energy consumption is addressed. Thus, sustainability emerges as a relational achievement rather than a fixed outcome.

6.3 Media Ecology and Audience Engagement

From the perspective of media ecology (McLuhan, 1964), the findings demonstrate that virtual exhibitions represent a new media environment that shapes cultural experience. Audiences interact differently with art in digital spaces, navigating exhibitions at their own pace and participating in online dialogues. These interactions transform art from a passive object of observation to an active medium of engagement.

Importantly, media ecology underscores the role of digital exhibitions in cultivating ecological consciousness. By framing digital participation as a sustainable act, virtual galleries foster environmental awareness and embed sustainability into cultural rituals. However, the diminished sensory experience and unequal access also reveal the limitations of digital media in fully replicating the embodied experience of physical exhibitions.

6.4 Sustainable Development and Ecological Consciousness

The findings also align with the sustainable development paradigm (United Nations, 2015), particularly SDG 12 (responsible consumption and production) and SDG 13 (climate action). Virtual exhibitions contribute to these goals by reducing material consumption and encouraging environmentally conscious cultural practices. Furthermore, increased inclusivity in access reflects SDG 10 (reduced inequalities).

At the same time, the findings highlight ethical challenges that complicate this alignment. Issues of digital inequality and potential greenwashing illustrate how sustainability goals may be unevenly realised across contexts. For instance, audiences in the Global South may face barriers to participation due to infrastructural limitations, raising questions about the equitable distribution of cultural sustainability benefits.

6.5 Implications for Practice

The findings and theoretical synthesis suggest several implications for practice:

- Holistic sustainability assessment – Institutions must evaluate the full ecological costs of virtual exhibitions, including digital infrastructures, rather than assuming that digital equals green.
- Hybrid exhibition models – Combining physical and virtual elements allows institutions to balance the strengths of embodied experience with the ecological benefits of digitalisation.

- Inclusive digital strategies – To address inequalities, institutions should invest in low-bandwidth options, mobile-friendly platforms, and partnerships with communities in low-resource contexts.
- Transparent communication – Clear disclosure of environmental impacts, both positive and negative, can prevent accusations of greenwashing and strengthen institutional credibility.

6.6 Broader Cultural Significance

Beyond practical implications, the findings contribute to understanding how the 4IR transforms cultural practices. Virtual galleries and green exhibitions represent a reconfiguration of art's role in society: art is no longer only a medium of aesthetic expression but also a site of ecological negotiation. By embedding sustainability into cultural practices, art institutions become agents of ecological modernisation, shaping not only cultural but also environmental futures.

6.7 Limitations and Future Research

While this study provides valuable insights, limitations must be acknowledged. The qualitative focus restricts generalisability, and the reliance on digital ethnography may exclude embodied aspects of art experience. Future research could employ mixed methods, combining life cycle assessments of digital infrastructures with audience surveys, to provide a more comprehensive evaluation of ecological impacts.

Additionally, further comparative research across Global North and Global South contexts is needed to address inequalities in access and sustainability benefits. This would align cultural research with broader global justice debates in sustainability studies.

7. Conclusion and future research directions

The Fourth Industrial Revolution presents both promise and complexity for reducing the environmental impact of art display. Virtual galleries and green exhibition practices can substantially reduce emissions from transportation and one-off set fabrication while expanding access to culture. However, digitalisation does not constitute an automatic green solution: server energy, device manufacturing, rebound effects, and inequitable access present real challenges. The integrating heuristic proposed here — combining socio-technical transitions thinking with LCA and new museology ethics — suggests a balanced path forward: prioritise evidence-based LCA planning, adopt modular and low-carbon staging strategies, invest in renewable digital infrastructure, and embed equity as a core principle.

Future research should pursue three lines. First, comparative LCAs that directly contrast large sets of exhibition scenarios (physical vs. hybrid vs. virtual) using standardised metrics would improve decision clarity for institutions. Second, longitudinal studies of audience engagement in high-fidelity virtual exhibitions versus physical visits would illuminate experiential trade-offs and their implications for conservation

and learning outcomes. Third, research into governance models and funding instruments that internalise environmental costs for cultural institutions could accelerate system-level transitions.

In the near term, cultural institutions can take pragmatic steps — modularity, LCA checklists, renewable hosting, and equitable digital access programs — to reduce exhibition footprints while maintaining their cultural mission. The 4IR does not force a binary choice between screens and objects; rather, it offers a toolbox for curators to craft more sustainable, accessible, and imaginative ways to present art in an era defined by environmental urgency.

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