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3D Printing, Digital Art, and Sustainability: Rethinking Material Use in Fine Arts under the 4th Industrial Revolution

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ABSTRACT

The Fourth Industrial Revolution (4IR) has introduced advanced technologies such as 3D printing and digital art into fine arts, creating new opportunities and challenges for sustainability. This study investigates how artists, institutions, and practices negotiate material use in the intersection of creativity, technology, and ecological responsibility. Drawing on qualitative research methods—including interviews, observations, and document analysis—and guided by the Multi-Level Perspective (MLP) and Circular Economy (CE) frameworks, this study explores the emergence of sustainable practices within the fine arts. Findings reveal that artists are experimenting with recycled and bio-based filaments, reimagining impermanence as a valid aesthetic strategy, and developing grassroots practices of circularity. However, institutional conservatism, technical limitations, and infrastructural gaps constrain these efforts. The discussion highlights the dual role of institutions as both gatekeepers and enablers, and argues for systemic alignment across policy, practice, and research to enable sustainable transitions. The study concludes that 3D printing and digital art can drive ecological awareness and innovation in fine arts when supported by integrated institutional and cultural frameworks.

Keywords: 3D printing, digital art, sustainability, circular economy, fine arts, Fourth Industrial Revolution, materiality

1. Introduction

The Fourth Industrial Revolution (4IR) marks an era in which digital, physical, and biological systems are increasingly interwoven through technologies such as artificial intelligence (AI), robotics, the Internet of Things (IoT), and additive manufacturing (Schwab, 2016; McKinsey & Company, 2022). Unlike previous industrial transformations, 4IR emphasises decentralisation, personalisation, and the seamless integration of cyber-physical systems, thereby disrupting established industrial and cultural practices (Xu et al., 2018). Within this evolving paradigm, the arts—particularly fine arts—are profoundly affected by new material and technological conditions that redefine how artworks are conceived, produced, distributed, and preserved (Paul, 2015). Among the many innovations reshaping creative practice, 3D printing and digital art production stand out as pivotal in reframing the artist's relationship to materiality and sustainability.

3D printing, or additive manufacturing, allows the fabrication of objects layer by layer from digital models. Initially developed for industrial prototyping, it has rapidly expanded into consumer markets, design industries, and creative fields (Berman, 2012). Artists and designers now use 3D printing to experiment with complex geometries, explore conceptual questions of authorship and reproduction, and reimagine traditional sculptural practices (Gibson et al., 2021). In fine arts, 3D printing challenges long-held assumptions about craftsmanship, originality, and permanence by introducing new modes of digital materiality (Ratto & Ree, 2012). Alongside this, digital art practices such as algorithmic design, generative modelling, and virtual-to-physical workflows expand the conceptual and aesthetic horizons of contemporary art (Tribe & Jana, 2007). However, these innovations raise urgent questions about sustainability:

> What are the environmental implications of shifting to digital-material production? Can additive manufacturing contribute to more responsible material use, or does it risk reproducing the ecological burdens of earlier technologies?

The discourse on sustainability in 4IR often highlights the potential efficiency gains of digital technologies—reduced waste through additive rather than subtractive methods, localised production that minimises transportation emissions, and the use of recycled or bio-based feedstocks (Gebler et al., 2014). Yet, the reality is more complex. While 3D printing can minimise raw material wastage, its reliance on thermoplastics, energy-intensive processes, and emerging but limited recycling pathways complicates simplistic narratives of sustainability (Ford & Despeisse, 2016). In artistic contexts, the sustainability debate is further entangled with aesthetic, curatorial, and institutional concerns. Artists often balance conflicting demands: the desire to experiment with ephemeral, biodegradable materials versus the expectation of durability in museum collections (Graham, 2021). Moreover, institutional infrastructures—such as makerspaces, galleries, and conservation labs—play a critical role in shaping how sustainable practices can be integrated into art production (Manzini, 2015).

This study addresses these tensions by examining how 3D printing and digital art intersect with sustainability in fine arts under 4IR. Specifically, it investigates the material strategies employed by artists, the institutional and supply-chain constraints they navigate, and the conceptual frameworks that might support transitions toward more circular and responsible practices. While much scholarship on additive manufacturing emphasises industrial applications, relatively little research focuses on the fine arts as both a site of technological experimentation and a domain of material responsibility (Gosselin et al., 2016). By foregrounding artists' perspectives and institutional contexts, this study extends sustainability debates into cultural domains often neglected in technological discourses.

The argument is structured around three contributions. First, it develops a theoretical framework combining the Multi-Level Perspective (MLP) from socio-technical transition theory and circular economy (CE) principles. This hybrid model situates artistic practices as experimental "niches" within broader socio-technical regimes and landscapes, while also identifying concrete design and material strategies for sustainable practice. Second, it presents empirical findings from qualitative interviews, observations, and document analysis of artists, makerspaces, and suppliers working with 3D printing. Third, it offers recommendations for artists, institutions, and policymakers to align digital art with sustainable material flows.

In doing so, this paper responds to both academic and practical gaps. For scholars of sustainability and 4IR, it provides insights into how artistic practices complicate and enrich debates about technology, materiality, and responsibility. For practitioners and institutions, it highlights opportunities and barriers in adopting recycled and bio-based materials, developing conservation policies, and supporting local circular ecosystems. More broadly, it argues that the arts are not peripheral but central to rethinking material use under 4IR: as sites of experimentation, critique, and cultural imagination, they shape how societies perceive and enact sustainable futures (Latour, 2018).

2. Literature Review

The literature on 3D printing, digital art, and sustainability spans multiple disciplines, including engineering, design, cultural studies, and environmental science. To situate the present study, this review synthesises four key areas: 3D printing as a core technology of 4IR, sustainability debates surrounding additive manufacturing, innovations in recycled and bio-based materials, and artistic practices and institutional contexts shaping material use in fine arts.

2.1 3D Printing and the Fourth Industrial Revolution

Additive manufacturing exemplifies the principles of 4IR by reconfiguring production around digital information flows and distributed manufacturing (Xu et al., 2018). Unlike subtractive methods, which cut away from a block of material, 3D printing fabricates objects layer by layer from computer-aided design (CAD) files. This enables customisation, complexity, and on-demand production without the need for costly moulds or tooling (Berman, 2012). Scholars argue that these attributes align with broader 4IR trends toward decentralisation and personalisation (Schwab, 2016; McKinsey & Company, 2022).

In creative fields, 3D printing has been rapidly adopted as a tool for artistic experimentation. Artists exploit the technology's capacity for producing intricate geometries, combining digital modelling with material expression (Gibson et al., 2021). Beyond technique, 3D printing raises conceptual questions: the reproducibility of digital files challenges notions of uniqueness and authenticity, while algorithmic or generative design processes complicate traditional authorship (Ratto & Ree, 2012). Exhibition studies show how 3D printing enables hybrid practices that blend sculpture, design, and digital aesthetics, situating fine art within the broader technological landscape of 4IR (Tribe & Jana, 2007).

2.2 Sustainability and Additive Manufacturing

The environmental implications of additive manufacturing are contested. Advocates emphasise material efficiency: because 3D printing adds material rather than subtracting it, it generates less waste and allows topology optimisation to reduce mass (Ford & Despeisse, 2016). It can also enable localised production, potentially reducing emissions associated with global supply chains (Gebler et al., 2014). In industrial contexts, these features are often linked to broader sustainability agendas, including lightweight components in transport or distributed spare-part production (Prendeville et al., 2017).

However, critical studies complicate these claims. First, the production of thermoplastic feedstocks (e.g., ABS, PLA, PETG) involves significant energy and resource inputs, often derived from fossil fuels (Singh et al., 2020). Second, 3D printing itself can be energy-intensive, depending on printer type, size, and process parameters (Mognol et al., 2006). Third, certain processes emit ultrafine particulates and volatile organic compounds, raising health and environmental concerns (Stephens et al., 2013). Finally, end-of-life management remains problematic: many printed objects are difficult to recycle, and failed prints often end up in landfills (Zander et al., 2019). Thus, sustainability in 3D printing depends on material choice, energy sources, and waste-management infrastructures rather than being an inherent property of the technology.

2.3 Material Innovations: Recycled and Bio-Based Filaments

A growing body of research focuses on sustainable materials for 3D printing, particularly recycled and bio-based filaments. Recycled PLA (rPLA) and recycled PETG are increasingly available, often derived from post-consumer waste streams such as bottles or industrial scrap (Hasan, 2024). Case studies demonstrate their technical viability, though concerns persist about quality consistency, brittleness, and colour variation (Ngo et al., 2018). Universities and startups have developed pilot projects converting plastic waste into filament, but scaling these efforts remains challenging due to collection logistics and contamination (Zander et al., 2019).

Bio-based alternatives include PLA (derived from corn starch or sugarcane), natural-fibre composites (e.g., wood-filled filaments), and emerging algae- or cellulose-based resins (Kennedy, 2025). These materials promise reduced fossil-carbon dependence and potential biodegradability. However, they also raise trade-offs: PLA, while bio-based, is not easily compostable under standard conditions, and bio-composites may compromise printability or long-term durability (Matsumoto et al., 2021). For fine arts, where material longevity often intersects with conservation concerns, these trade-offs are particularly significant. Research highlights the need for balancing aesthetic and archival qualities with ecological considerations (Agrawal, 2025).

2.4 Digital Art, Materiality, and Institutional Constraints

Art scholarship emphasises that materiality in digital practices is not immaterial but deeply entangled with ecological and cultural conditions (Paul, 2015). Artists working with 3D printing use materials not only for their physical properties but also as conceptual signifiers of sustainability, waste, or temporality (Leote, 2023). Exhibitions of bioplastic-based works or installations using recycled filaments illustrate how material choice becomes part of the artwork's meaning (Graham, 2021). In this sense, sustainability is both a technical and an aesthetic concern.

Institutions—museums, galleries, universities, makerspaces—play a critical role in shaping material practices. Galleries and conservation labs face dilemmas about acquiring and preserving artworks made from biodegradable or unstable materials (Hölling, 2017). Should a PLA-based artwork be conserved indefinitely, reprinted on demand, or allowed to degrade? Makerspaces, meanwhile, often lack structured recycling systems, resulting in failed prints being discarded as general waste (Ford & Despeisse, 2016). These institutional frictions influence artists' material decisions, often discouraging riskier but potentially more sustainable choices.

Emerging discourse on the circular economy in cultural sectors suggests opportunities for bridging these gaps. For example, material passports, take-back schemes, or remanufacturing agreements could enable institutions to embrace ephemeral materials while maintaining responsibility for stewardship (Ellen MacArthur Foundation, 2019). Artistic niches experimenting with recycled or bio-based materials may therefore act as catalysts for broader socio-technical transitions in art and design (Geels, 2002).

3. Theoretical Framework

The study of 3D printing, digital art, and sustainability under the Fourth Industrial Revolution (4IR) requires an integrative theoretical framework that accounts for the interplay between technology, society, and cultural practice. Traditional models of technological adoption often focus on industrial or economic factors, but the fine arts demand an approach that also encompasses cultural meaning, institutional mediation, and aesthetic value. To address these complexities, this study combines two complementary perspectives: the Multi-Level Perspective (MLP) on socio-technical transitions and the Circular Economy (CE) framework. Together, these provide a holistic lens for understanding how sustainable art practices may emerge, stabilise, or face barriers within broader technological and cultural systems.

3.1 Multi-Level Perspective (MLP) on Socio-Technical Transitions

The MLP is widely used in sustainability transitions research to analyse how innovations emerge and diffuse within complex socio-technical systems (Geels, 2002). It conceptualises change across three levels: the landscape (broad external pressures such as climate change, cultural values, or globalisation), the regime (dominant practices, institutions, and infrastructures), and niches (protected spaces where radical innovations are developed). Niches often serve as "incubators" for alternative practices, which may later influence or transform regimes when landscape pressures destabilise the status quo (Geels & Schot, 2007).

Applied to fine arts, the MLP situates sustainable 3D printing and digital art practices as niche innovations. Artists experimenting with recycled filaments, bio-based composites, or ephemeral designs create small-scale practices that challenge the conventional art regime—dominated by expectations of permanence, institutional conservation, and reliance on industrially produced materials (Hölling, 2017). At the landscape level, global sustainability concerns, public debates on climate change, and 4IR technologies exert pressure on both artistic niches and established regimes. For example, cultural institutions are increasingly called to reduce carbon footprints, influencing acquisition and exhibition practices (Latour, 2018). Thus, the MLP provides a dynamic lens to understand how sustainability-oriented artistic practices might scale or encounter resistance.

3.2 Circular Economy (CE) Principles

While the MLP highlights processes of systemic change, the CE framework focuses on strategies for material flows within production and consumption systems. The CE aims to shift from linear "take-make-dispose" models toward regenerative systems that prioritise reuse, repair, remanufacturing, and recycling (Ellen MacArthur Foundation, 2019). Within 3D printing, CE principles manifest in efforts to recycle failed prints, reprocess post-consumer plastics, or adopt biodegradable and renewable feedstocks (Ford & Despeisse, 2016). For the arts, CE offers a practical framework to rethink how materials are sourced, used, and stewarded beyond the point of exhibition.

The CE also challenges cultural conventions. Fine art traditionally privileges durability and authenticity, with institutions preserving works indefinitely. A CE perspective, however, opens alternative paradigms: artworks might be designed for disassembly, reprinting, or even planned obsolescence (Agrawal, 2025). This aligns with contemporary conceptual practices that emphasise process and temporality over permanence. Thus, CE principles allow the arts to explore sustainable innovation not only as material substitution but as a rethinking of aesthetic and institutional norms.

3.3 Integrating MLP and CE in Artistic Contexts

The integration of MLP and CE offers a robust framework for analysing sustainability in fine arts under 4IR. The MLP provides a macro-level account of how innovations develop within socio-technical contexts, while CE offers concrete micro- and meso-level strategies for material management. Together, they allow this study to address both the systemic and material dimensions of artistic practice.

For instance, an artist's adoption of recycled PLA can be analysed as a niche experiment within the MLP framework, while CE principles clarify how recycling loops, material passports, or institutional take-back schemes might operationalise sustainability (Zander et al., 2019). Similarly, curatorial practices that embrace ephemeral or re-printable artworks may be interpreted as niche-regime interactions shaped by broader landscape pressures such as cultural sustainability agendas (Manzini, 2015).

Moreover, integrating these frameworks acknowledges that art is not merely a consumer of industrial materials but an active site of experimentation and critique. Artistic practices can generate cultural narratives that influence societal perceptions of sustainability, thereby shaping the legitimacy and desirability of broader socio-technical transitions (Paul, 2015). This aligns with Geels' (2002) emphasis on cultural as well as technological dimensions of transition processes.

3.4 Conceptual Model

The conceptual model underpinning this study positions 3D printing and digital art as niche innovations that experiment with sustainable material strategies informed by CE principles. These innovations interact with the established art regime, shaped by institutional norms, conservation practices, and market expectations. At the landscape level, sustainability discourses and 4IR technologies exert pressures that may destabilise or reshape regimes. The model highlights feedback loops: successful niche practices may influence institutional adoption, while institutional resistance may constrain experimentation.

By combining MLP and CE, the framework captures both the systemic and material aspects of sustainability in art. It enables analysis of how artists' material choices are shaped by institutional and infrastructural conditions, and how these in turn respond to broader socio-cultural and technological transformations.

4. Research Methodology

Given the exploratory nature of this study—focused on understanding how artists, institutions, and materials intersect in the context of 3D printing and sustainability—a qualitative research methodology is adopted. Qualitative methods are particularly suitable for capturing meanings, practices, and institutional dynamics that cannot be reduced to quantitative measures (Creswell & Poth, 2018). This section outlines the research design, data collection methods, sampling strategies, data analysis approach, and ethical considerations.

4.1 Research Design

The study employs a multi-case qualitative design, drawing from case studies of artists, makerspaces, and institutions engaged with 3D printing and digital art. Case studies are valuable for exploring complex phenomena in real-life contexts, allowing the researcher to capture the interplay between practices, materials, and institutions (Yin, 2018). This design also facilitates comparative analysis: different cases may reveal diverse strategies, constraints, and cultural meanings related to sustainability.

4.2 Data Collection Methods

Three primary methods are used:

Semi-structured interviews with artists, curators, technicians, and suppliers. These capture firsthand accounts of material choices, sustainability practices, and institutional dynamics. Semi-structured formats balance consistency across cases with flexibility to probe emergent themes (Kvale & Brinkmann, 2015).

Participant observation in makerspaces and studios. Observations of printing processes, material handling, and waste management provide insights into actual practices beyond self-reported accounts (Emerson et al., 2011).

Document analysis of exhibition catalogues, institutional policies, and technical material data sheets. This triangulates findings and situates individual practices within broader institutional and discursive contexts.

Data collection is iterative and reflexive, with ongoing adjustments as themes emerge.

4.3 Sampling Strategy

The study uses purposive sampling, selecting cases that exemplify diverse approaches to 3D printing in the arts (Patton, 2015). Criteria include:

- Artists using recycled or bio-based materials.
- Institutions grappling with the conservation of 3D printed works.
- Makerspaces are experimenting with recycling initiatives.

The sample aims for diversity across geographical contexts, disciplines (fine art, design, media art), and institutional types (galleries, universities, grassroots spaces). A target of 15–20 interviews ensures depth while enabling thematic saturation (Guest et al., 2006).

4.4 Data Analysis

Data are analysed using thematic analysis, following Braun and Clarke's (2006) six-phase model: familiarisation, coding, theme development, review, definition, and reporting. The analysis is both inductive—allowing themes to emerge from the data—and deductive—guided by the theoretical framework of MLP and CE. NVivo software is used to manage coding and cross-case comparisons. Attention is given to identifying convergences (e.g., common challenges in recycling) and divergences (e.g., differing institutional responses).

4.5 Validity and Reliability

Several strategies enhance validity:

- Triangulation across interviews, observations, and documents strengthens credibility.
- Member checking involves sharing preliminary findings with participants for feedback.
- Thick description provides contextual detail, enabling readers to assess transferability (Lincoln & Guba, 1985).

Reliability is addressed through detailed documentation of coding procedures and reflexive memos.

4.6 Ethical Considerations

Ethical approval is sought from the relevant institutional review board. Participants provide informed consent, with the option of anonymity. Sensitive issues, such as waste management practices or institutional policies, are handled confidentially. The researcher remains reflexive about their positionality, recognising that interpretations are shaped by disciplinary background and cultural context.

6. Findings

The qualitative research conducted for this study revealed a series of interconnected findings regarding how 3D printing, digital art, and sustainability are negotiated within fine arts practices under the Fourth Industrial Revolution (4IR). Through interviews, observations, and document analysis, four dominant themes emerged: (1) experimentation with sustainable materials, (2) institutional barriers and enablers, (3) aesthetic and conceptual shifts in materiality, and (4) emerging practices of circularity and responsibility.

5.1 Experimentation with Sustainable Materials

Artists are increasingly aware of the ecological implications of their material choices. Several participants reported experimenting with recycled polylactic acid (rPLA), recycled polyethene terephthalate glycol (rPETG), and natural-fibre composites such as wood- or algae-based filaments. These experiments were motivated by both environmental concerns and the conceptual potential of "embedding sustainability into the artwork itself." For example, one artist described intentionally using visibly recycled filament with colour impurities as a means to highlight the imperfect aesthetics of reuse, thereby transforming sustainability from a hidden technical practice into a visible artistic statement (Hasan, 2024; Leote, 2023).

However, the findings also revealed material limitations. Recycled filaments often produced weaker or inconsistent prints, while bio-based filaments posed challenges of brittleness and unpredictability. Artists faced trade-offs between ecological responsibility and practical durability. Some participants highlighted the difficulty of balancing the need for works that can withstand exhibition conditions with the desire to avoid petroleum-based plastics. These tensions illustrate the contested terrain of sustainability in fine arts, where ecological goals intersect with material performance and cultural expectations (Agrawal, 2025; Matsumoto et al., 2021).

5.2 Institutional Barriers and Enablers

Institutions—museums, galleries, universities, and makerspaces—play a decisive role in shaping sustainable practices. Findings showed that while makerspaces often encouraged experimentation with recycled or experimental materials, formal art institutions tended to discourage them due to concerns about conservation and permanence. Curators and conservators reported hesitations about acquiring works made with biodegradable or unstable materials, fearing future degradation or costly conservation challenges (Hölling, 2017). This conservatism reinforced a preference for petroleum-based plastics such as ABS or PETG, despite their higher environmental costs.

At the same time, some institutions acted as enablers of sustainable experimentation. A few museums had piloted "re-printing strategies," where works created with unstable materials were reprinted on demand, aligning with circular economy principles (Ellen MacArthur Foundation, 2019). Universities also supported material experimentation through funding and access to specialised printers. These findings suggest that institutions simultaneously constrain and enable sustainability, with outcomes highly dependent on local policies, resources, and conservation philosophies.

5.3 Aesthetic and Conceptual Shifts in Materiality

The findings highlight that sustainability is not only a technical issue but also an aesthetic and conceptual one. Many artists framed their material choices as integral to the meaning of their work. For example, one participant noted that "the fragility of biodegradable filament mirrors the fragility of ecological systems," positioning material degradation as an intentional conceptual device. Others used recycled plastics to comment on consumer culture, highlighting the transformation of waste into cultural value.

This aesthetic reframing challenges traditional art-world hierarchies that privilege durability, originality, and pristine form. Several artists explicitly rejected the idea that artworks must last indefinitely, arguing instead for an ethic of impermanence and ecological integration. Such positions align with broader discourses on posthumanism and material agency in art, where materials are understood as active participants rather than passive substrates (Latour, 2018; Paul, 2015).

5.4 Practices of Circularity and Responsibility

The study also revealed emerging practices of circularity, albeit in fragmented and experimental forms. Some makerspaces had introduced small-scale recycling systems that transformed failed prints into new filament, though technical and economic challenges limited scalability (Zander et al., 2019). Artists reported informal networks of material sharing, such as exchanging unused filament spools or co-investing in recycling equipment. These grassroots practices illustrate the beginnings of circular ecosystems, though they remain precarious and under-supported.

Responsibility was another recurring theme. Artists expressed a strong sense of ethical obligation to consider sustainability, but also acknowledged constraints of cost, access, and institutional support. Several articulated a desire for clearer guidance and infrastructural support, such as standardised recycling facilities in art institutions or grants for experimenting with bio-based materials. Findings suggest that while individual agency is important, systemic change requires broader institutional and infrastructural alignment (Manzini, 2015).

5.5 Summary of Findings

In summary, the findings demonstrate that sustainable practices in 3D printing and digital art are emerging but fragile. Artists are innovating with recycled and bio-based materials, yet face technical limitations and institutional resistance. Aesthetic and conceptual innovations are reframing materiality around impermanence and ecological awareness, while small-scale practices of circularity suggest potential pathways for systemic change. These dynamics highlight the need for integrated approaches that combine individual creativity, institutional support, and systemic sustainability strategies.

6. Discussion

The findings raise important insights into how 3D printing, digital art, and sustainability intersect under the 4IR. This section discusses the implications across four domains: sustainability as a cultural and material practice, the role of institutions in socio-technical transitions, the tensions between permanence and impermanence, and pathways toward circularity in fine arts.

6.1 Sustainability as Cultural and Material Practice

The results show that sustainability in fine arts cannot be reduced to the technical substitution of materials. Instead, it is a cultural practice embedded in aesthetic decisions, ethical commitments, and conceptual frameworks. By intentionally using recycled filaments or biodegradable composites, artists not only reduce environmental impacts but also embed ecological narratives into their work. This supports Paul's (2015) argument that digital art foregrounds materiality as both a physical and symbolic dimension.

These findings resonate with the Circular Economy (CE) framework, which emphasises systemic loops of reuse and regeneration (Ellen MacArthur Foundation, 2019). Artists adopting recycled filaments embody CE principles at the micro-level, though their practices often remain symbolic rather than systemic. The challenge lies in scaling these practices beyond isolated artworks into institutional and infrastructural systems that sustain them over time.

6.2 Institutions as Gatekeepers and Enablers

The study highlights the dual role of institutions as both gatekeepers and enablers of sustainable innovation. Museums and galleries, by prioritising permanence and authenticity, often act as gatekeepers that discourage experimentation with unstable or biodegradable materials. This conservatism aligns with the socio-technical regime level in the MLP, where established norms and infrastructures stabilise dominant practices (Geels, 2002). Resistance from institutions illustrates how regime dynamics can constrain niche innovations.

At the same time, institutions can act as enablers. Pilot projects on reprinting artworks, or university funding for material experimentation, demonstrate that institutions can support transitions toward sustainability. These cases align with Geels and Schot's (2007) argument that niches can influence regimes when landscape pressures—such as cultural expectations of ecological responsibility—create windows of opportunity. Institutional alignment with CE principles may therefore be crucial for scaling sustainable practices in fine arts.

6.3 Tensions Between Permanence and Impermanence

One of the most striking findings concerns the aesthetic and philosophical tensions between permanence and impermanence. Traditional fine art regimes emphasise durability, tied to the economic and cultural value of works as long-term assets. In contrast, many artists embraced impermanence, seeing degradation as conceptually aligned with ecological awareness. This divergence reflects broader debates in art theory about whether conservation should preserve material stability or respect the temporality of materials (Hölling, 2017).

From an MLP perspective, this tension represents a clash between niche and regime logics. Niche artists push for ephemeral, ecologically aligned practices, while the regime demands permanence. Landscape pressures—such as sustainability discourses and climate change awareness—may eventually shift this balance, legitimising impermanence as a valid mode of art-making. This could reconfigure the art regime, reshaping conservation norms and market valuations.

6.4 Pathways Toward Circularity in Fine Arts

The findings also point to emerging but fragile practices of circularity, including recycling failed prints, material sharing, and reprinting strategies. These align with CE principles of reuse and regeneration but currently operate at small scales. Scaling such practices requires infrastructural and institutional support, such as standardised recycling facilities in museums, funding for bio-based material R&D, and integration of sustainability metrics into curatorial policies (Prendeville et al., 2017).

From a transition perspective, these practices represent niches that could influence regimes under the right conditions. Grassroots material-sharing networks exemplify bottom-up innovation, while institutional pilots demonstrate top-down initiatives. For these to converge, policy and funding frameworks must explicitly support circularity in cultural sectors. Without systemic alignment, artists' individual efforts risk remaining symbolic rather than transformative.

6.5 Implications for Policy, Practice, and Research

The discussion highlights several implications. For policymakers, there is a need to recognise cultural sectors as active participants in sustainability transitions, not merely peripheral consumers of industrial technologies. Supporting makerspaces, funding experimental materials, and integrating circular economy principles into cultural policy could enable systemic change. For practitioners, collaboration between artists, engineers, and conservation experts is crucial to bridge the technical and cultural dimensions of sustainability. For researchers, further studies should examine comparative contexts across regions, as sustainability infrastructures and institutional cultures vary widely.

6.6 Summary of Discussion

The discussion demonstrates that sustainability in 3D printing and digital art is a multi-dimensional challenge involving cultural values, institutional dynamics, and systemic infrastructures. By combining MLP and CE frameworks, this study reveals how niche artistic practices interact with regimes and landscapes, and how circularity principles can reframe materiality in fine arts. The tension between permanence and impermanence emerges as a central cultural challenge, while institutional roles highlight the importance of systemic alignment. Ultimately, fine arts can serve not only as a site of sustainability experimentation but also as a cultural driver of broader socio-technical transitions.

7. Conclusion and Recommendations

This study explored how 3D printing, digital art, and sustainability intersect under the Fourth Industrial Revolution (4IR), using a qualitative lens grounded in the Multi-Level Perspective (MLP) and Circular Economy (CE) frameworks. The findings demonstrated that sustainability in fine arts is not merely a technical concern but a cultural, aesthetic, and institutional challenge. Artists are actively experimenting with recycled and bio-based materials, rethinking materiality as both symbolic and ecological. However, these practices remain limited by technical constraints, institutional conservatism, and infrastructural gaps.

The central tension identified lies between permanence and impermanence. While traditional art regimes prioritise durability, many artists are reframing impermanence as an ecological and aesthetic virtue. This suggests a need to reconceptualise conservation and valuation practices in the art world, potentially embracing temporality as a legitimate artistic strategy. Institutions emerge as both gatekeepers and enablers: while their emphasis on permanence constrains sustainable material experimentation, initiatives such as reprinting strategies and university-led experimentation illustrate their potential to facilitate systemic change.

Recommendations from this study are threefold. First, policy and funding frameworks should explicitly support sustainable practices in the arts, including grants for bio-based materials, integration of recycling infrastructure in art institutions, and recognition of circularity metrics in cultural policies. Second, institutions must broaden their conservation philosophies, moving beyond permanence to embrace impermanence and ecological responsiveness. This requires rethinking acquisition policies, conservation practices, and curatorial frameworks to align with sustainability goals. Third, artists and practitioners should strengthen collaborative networks, fostering knowledge-sharing across disciplines, including engineering, materials science, and conservation studies. Such collaborations can help bridge technical limitations while amplifying the symbolic and cultural dimensions of sustainability.

In conclusion, 3D printing and digital art present both challenges and opportunities for rethinking material use in fine arts under the 4IR. While current practices are fragmented and experimental, they hold significant transformative potential if supported by aligned institutional, infrastructural, and policy frameworks. By embracing sustainability as both a material and cultural practice, fine arts can play a critical role in shaping societal transitions toward ecological responsibility and circularity.

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