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Digital Fitting for Resource Optimization: Hybrid Practices for Sustainable Accessory Design

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ABSTRACT

Digital fitting technologies have transformed fashion retail through virtual visualisation and consumer engagement, yet their potential in early-stage accessory product development remains underexplored. Accessories involve complex materials, specialised manufacturing processes and knowledge networks requiring collaboration between human expertise and digital systems. This study investigates digital fitting as a human-centred knowledge infrastructure supporting collaborative design and decision-making. The research integrates Service-Dominant Logic (S-D Logic), Service Science (SS) and the Viable Systems Approach (VSA), viewing value as emerging from the integration of resources, competences and knowledge across interconnected actors. The paper develops a conceptual framework through ecosystem mapping, relational knowledge modelling, practice-informed expert reflection, and scenario-based discussion. Ecosystem mapping identifies the relationships among designers, manufacturers, suppliers, and technical specialists, while relational knowledge modelling integrates material properties, manufacturing constraints, and production information within a Digital Twin perspective. Practice-informed reflections and representative design scenarios are used to examine recurring coordination challenges and discuss the conceptual applicability of collaborative digital fitting throughout accessory development, thereby strengthening methodological transparency, analytical coherence, and conceptual traceability. The findings indicate that the main obstacle to accessory innovation is knowledge fragmentation. Material intelligence, manufacturing expertise and technical constraints often become available only after physical prototyping, increasing iterations and uncertainty. The proposed framework reinterprets the Digital Twin as a relational socio-technical environment where digital fitting enhances human judgement through shared knowledge and earlier informed decisions. By strengthening collaboration and reducing uncertainty before production, the framework supports resource-efficient accessory development and contributes to Sustainable Development Goal 12 on Responsible Consumption and Production.

Keywords: Digital fitting, Service-dominant logic, Service science, Viable systems approach, Accessory design

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INTRODUCTION

Digital technologies have progressively evolved from tools supporting fashion practice into infrastructures that shape how fashion is conceived, developed, manufactured, and circulated. Rather than representing a simple technological transition, the current digital transformation is reconfiguring design processes, production logics, and organisational structures. Designers, manufacturers, suppliers, materials, and data systems increasingly operate within interconnected socio-technical environments where creative and industrial decisions emerge through continuous interactions between human expertise, material constraints, and computational infrastructures (Casciani et al., 2022; Särmäkari & Vänskä, 2022). Over the past decade, digital fashion research has largely concentrated on consumer-facing innovations, including virtual try-ons, immersive retail environments, digital garments, and augmented reality applications (Boughlala & Smelik, 2024; Chan et al., 2024). While these developments have transformed the experiential and communicative dimensions of fashion, the role of digital technologies within upstream design and manufacturing processes remains comparatively underexplored. This limitation is particularly evident in accessory design, where digital fitting has received far less theoretical and operational attention than in apparel. Unlike garments, accessories such as leather goods, jewellery, eyewear, belts, and hardware-intensive products require extremely high levels of geometric precision, material accuracy, and mechanical integration from the earliest stages of development (Choi, 2022; Lyu et al., 2025). Even minimal inaccuracies can compromise functionality, manufacturability, durability, and assembly feasibility. As a result, accessory design continues to rely heavily on iterative physical prototyping to validate technical performance before production.

Although physical prototypes remain essential for evaluating material behaviour, structural resistance, and assembly performance, repeated iterations increase development time, resource consumption, production costs, and environmental impact (Wulff & Gustafsson, 2026). This dependence exposes a broader structural gap between digital design environments and the manufacturing knowledge required for industrial realisation. This paper argues that digital fitting should be understood not simply as a simulation technology, but as an infrastructure that coordinates creative intent, material intelligence, and production knowledge throughout accessory development.

Drawing on Service-Dominant Logic, Service Science, and the Viable Systems Approach, the study proposes a Digital Twin-oriented perspective that repositions digital fitting as a relational system supporting coordination across the entire design-to-production continuum (Golinelli et al., 2010).

To address this research gap, the paper adopts a conceptual and practice-informed research approach aimed at reinterpreting digital fitting within accessory design ecosystems rather than evaluating a specific technological implementation. The study develops progressively through ecosystem mapping, relational knowledge modelling, practice-informed expert reflection, and the discussion of representative accessory design scenarios. Together, these analytical stages provide a structured basis for examining how manufacturing knowledge can be integrated into Digital Twin-oriented collaborative design processes before physical prototyping.

LITERATURE REVIEW

The academic discourse surrounding digital fashion is characterized by a rapidly evolving and still fragmented landscape where technological innovation has often advanced more quickly than theoretical frameworks.

Rather than constituting a coherent field, digital fashion emerges as a convergence of multiple trajectories involving representation, experiential consumption, computational design, industrial transformation, and infrastructural reconfiguration (Boughlala & Smelik, 2024).

This review is organized around three interconnected areas: digital fashion as an experiential and representational system; digital transformation as infrastructural reconfiguration; and hybrid design practices, materiality, and simulation limitations in accessory design.

Digital Fashion as Experiential and Representational System

Early studies on digital fashion largely interpreted digitalization as an expansion of fashion's communicative and symbolic dimensions. Digital technologies extend the possibilities of visual representation, mediated consumption, and identity construction across digital environments (Boughlala & Smelik, 2024). Immersive retail systems, virtual garments, and augmented reality applications have reshaped how fashion is perceived and experienced (Crepax & Liu, 2024). In these contexts, digital garments function as standalone immaterial product categories where value is generated through interaction, visibility, and participation in attention-driven platform economies (Chan et al., 2024).

However, from a design and production perspective, such approaches tend to underrepresent the infrastructural, material, and mechanical conditions that determine feasibility and manufacturability. S-D Logic conceptualizes value as something emerging through interaction, resource integration, and co-creation among multiple actors rather than residing within products themselves (Vargo & Lusch, 2008). Within this framework, technologies function less as isolated representational tools and more as relational infrastructures enabling coordination among designers, manufacturers, and suppliers (Maglio & Spohrer, 2008; Golinelli et al., 2012).

Digital Transformation as Infrastructural Reconfiguration

A second strand of literature shifts attention from representation toward the infrastructural implications of digital transformation. Here, digitalization is interpreted as a systemic reconfiguration affecting supply chains, organizational structures, production models, and sustainability strategies (Casciani et al., 2022). Computational environments are no longer external supports applied to existing workflows, but constitutive elements of design and manufacturing practices themselves. From an S-D Logic perspective, this represents a shift from linear production chains toward ecosystems of value co-creation where actors operate as resource integrators within relational systems (Vargo & Lusch, 2008). This relational interpretation is particularly relevant for digital fitting systems, which may be reconsidered as

infrastructural mechanisms capable of connecting design intent with material and industrial conditions.

Hybrid Design Practices and Distributed Agency

Contemporary design practices unfold within hybrid environments where physical and computational systems coexist and continuously interact (Tepe & Koohnavard, 2023). Generative tools and algorithmic environments influence aesthetic directions, technical possibilities, and decision pathways rather than merely supporting design activity (Särmäkari & Vänskä, 2022). As a result, agency becomes distributed across networks of human and non-human actors, including designers, software systems, datasets, material constraints, and industrial infrastructures (Barile & Polese, 2010). Design therefore becomes a process of negotiation among technical knowledge, computational mediation, and material conditions. However, materially constrained sectors like accessory design remain comparatively underexplored, as most literature continues to focus on garments and digital aesthetics.

Materiality, Simulation Limits, and the Accessory Design Gap

A recurring limitation in digital fashion literature concerns the uneven development of material simulation capabilities. Although significant progress has been achieved in body-data integration and garment modelling (Lyu et al., 2025), the accurate simulation of rigid and mechanically constrained structures remains comparatively limited (Choi, 2022). This gap is particularly critical for accessories, whose functionality, durability, assembly, and manufacturability depend on precise material properties, geometries, tolerances, and component interactions. High-resolution visualisation may therefore coexist with limited predictive capacity regarding mechanical performance and industrial feasibility, leaving accessory development reliant on iterative physical prototyping and its associated costs in time, labour, materials, and environmental resources. This dependence also exposes a broader infrastructural fragmentation, as manufacturing expertise and material knowledge remain distributed across specialised actors and disconnected systems. Accessory development involves highly specific material and mechanical constraints that are difficult to reproduce through conventional digital fitting. In eyewear, the interface between acetate frames and metal hinges requires precise alignment, as thermal deformation and post-cure shrinkage can affect hinge anchoring, while lens-groove depth, joint friction, and temple flexibility must remain within narrow tolerances; even a 0.05 mm deviation in groove geometry may compromise lens retention under stress. In fine jewellery, structural integrity similarly depends on accurate stone-setting geometries, casting shrinkage, joint tolerances, and micro-mechanical components, with prongs, clasps, articulated joints, and wall thicknesses designed to withstand repeated mechanical loads; precious-metal casting may involve approximately 1.5–3.0% contraction depending on alloy and geometry. Leather goods and belts introduce further complexity because anisotropic, nonlinear leather interacts with rigid reinforcements

and metallic hardware such as buckles, studs, and turn-locks, determining force distribution, stitch-line tension, deformation, drape, and wear. A digital fitting infrastructure must therefore capture these material interactions and mechanical constraints, including tension propagation through sewing margins and deformation around rigid interfaces, to provide meaningful evidence of manufacturing and functional feasibility.

Platformisation, Temporality, and Infrastructural Friction

The increasing platformisation of fashion systems has introduced new organizational and temporal dynamics. Digital infrastructures accelerate communication while generating new forms of friction linked to interoperability and data reliability (Repenning, 2024). Consequently, design workflows become characterized by overlapping rhythms of acceleration and delay. Within accessory design, these temporal dynamics are particularly significant because early-stage design decisions must account for downstream production constraints. Under such conditions, fragmented information flows directly affect feasibility, manufacturing efficiency, and resource optimization. Platforms function as relational ecosystems in which actors exchange resources, competencies, and knowledge through continuous interaction (Vargo & Lusch, 2008).

Sustainability, Systemic Trade-offs, and Ethical Supply Chains

Sustainability outcomes depend on how technologies are configured and integrated within broader production ecosystems (Wulff & Gustafsson, 2026). Digital prototyping can reduce physical waste associated with repeated sampling and material testing, yet it also introduces environmental costs connected to computational infrastructures and energy consumption. Within accessory design, the sustainability potential of digital systems depends largely on their capacity to integrate material intelligence and manufacturing constraints early in the design process, reducing unnecessary physical iterations.

This system-level optimization directly supports ethical supply chain practices and compliance with UN Sustainable Development Goal 12. By digitizing material certifications—such as the Leather Working Group (LWG) standards for tanneries and the Responsible Jewellery Council (RJC) traceability metrics for precious metals—the relational digital twin allows brands to audit ethical compliance dynamically during the design phase. Rather than verifying sourcing ex-post, designers can select certified 'liquefied' materials directly from a verified database, ensuring that ethical compliance, chemical safety, and carbon footprint tracking are built directly into the product's digital DNA.

Toward Digital Fitting as Relational Infrastructure

Overall, the literature reveals an ongoing yet incomplete transition from digital fashion understood as representational experience toward digital fashion conceived as an infrastructural and relational condition

(Casciani et al., 2022). The persistent gap between visual representation and physical feasibility highlights the need for frameworks capable of integrating design intent, material intelligence, and industrial constraints within unified informational environments. Within this context, this study conceptualizes digital fitting not as a purely representational tool, but as a relational infrastructural mechanism embedded within a Digital Twin ecosystem (Casciani et al., 2022). In this configuration, digital fitting functions as a mediating system connecting designers, manufacturers, materials, and computational infrastructures through continuous information exchange, supporting earlier validation processes and more integrated forms of value co-creation.

Research Approach

This study follows a conceptual and practice-informed research approach grounded in interdisciplinary literature on digital fashion, accessory design, and service ecosystems. Rather than testing an implemented Digital Twin application, the paper develops an interpretative framework explaining how manufacturing knowledge can be integrated into collaborative digital fitting environments during accessory development.

The analytical process unfolds through four interconnected stages. First, ecosystem mapping identifies the actors participating in accessory design and manufacturing and the relationships through which technical knowledge is exchanged across the development process. Second, relational knowledge modelling organises material intelligence, manufacturing constraints, and production information within a Digital Twin-oriented perspective. Third, practice-informed expert reflection, supported by established professional expertise in accessory product development, is used to interpret recurring coordination and feasibility challenges identified in the literature. Finally, representative accessory design scenarios are discussed to examine the conceptual coherence and practical relevance of the proposed Reflective Digital Fitting framework.

CONCEPTUAL FRAMEWORK

This study reconceptualises digital fitting as an infrastructural capability embedded within socio-technical design ecosystems, rather than as a standalone technology for virtual simulation. Instead of reducing fitting environments to tools for visualising products before production, the proposed framework positions them as relational infrastructures through which design knowledge, material intelligence, manufacturing constraints, and organisational decision-making are continuously negotiated and synchronised. Within accessory design, value does not reside in the technology itself but emerges through the coordinated interaction of designers, computational platforms, production specialists, materials, and industrial processes (Boughlala & Smelik, 2024).

To explain this relational dynamic, the framework combines Service-Dominant Logic (SDL), Service Science (SS), and the Viable Systems

Approach (VSA) into a single systemic perspective on digital fitting across the design-to-production continuum (Vargo & Lusch, 2004; Golinelli et al., 2010). Rather than treating these theories as parallel explanatory models, they are mobilised as complementary lenses that illuminate different yet interconnected dimensions of the same socio-technical infrastructure (Golinelli et al., 2010).

From the perspective of Service-Dominant Logic, value is created through the integration and application of specialised competences rather than embedded within tangible products. Artefacts become vehicles for mobilising knowledge, expertise, and collaborative capabilities, shifting the focus of design from the production of objects to the orchestration of value-creating interactions throughout development processes (Vargo & Lusch, 2004). Within digital fitting, design decisions acquire value insofar as they activate exchanges between creative, technical, and manufacturing resources.

Service Science expands this view by conceptualising organisations as interconnected service systems composed of heterogeneous actors linked through technological, organisational, and social relationships (Golinelli et al., 2010; Maglio & Spohrer, 2008). Innovation therefore depends on the capacity of these actors to configure distributed resources into coherent operational systems. Applied to accessory development, digital fitting becomes the collaborative environment where computational models, material data, human expertise, and production intelligence continuously interact to generate increasingly feasible design configurations.

The Viable Systems Approach provides the systemic architecture that integrates these relational processes into a broader theory of organisational adaptability (Golinelli et al., 2010; Barile & Polese, 2010). VSA argues that viability depends on an organisation's ability to maintain consonance with its surrounding environment through adaptive relationships and continuous systemic reconfiguration. From this perspective, value co-creation is understood not as a sequence of exchanges but as an emergent property of interactions among interdependent actors operating within evolving ecosystems. Digital fitting consequently becomes a governance infrastructure capable of aligning creative intentions, technical capabilities, and manufacturing requirements across multiple organisational scales.

The convergence of SDL, SS, and VSA reveals three progressive analytical shifts. First, SDL relocates design from a goods-centred paradigm to a competence-centred logic in which knowledge integration constitutes the primary source of value. Second, Service Science reframes innovation as the coordination of distributed human and technological resources within interconnected service systems. Third, VSA situates these interactions within a viable ecosystem, demonstrating that sustainable value creation depends on the quality, adaptability, and coherence of relationships among actors rather than on isolated technological performance. Within this integrated perspective, digital fitting is conceptualised as a viable service infrastructure that enables recursive exchanges of information throughout accessory development. Its function extends beyond validating completed prototypes; it continuously mediates between creative exploration and production

feasibility through iterative cycles of feedback, adjustment, and resource integration. Design knowledge is therefore not transferred linearly from concept to production but progressively transformed through interaction with material and industrial intelligence. This interpretation is particularly significant in accessory design, where manufacturability depends on precise material tolerances, construction logics, hardware integration, and assembly sequences. Compared with apparel, accessories allow minimal geometric approximation, making the translation from digital model to physical artefact especially vulnerable to technical discontinuities. This study conceptualises that structural discontinuity as the Material Feasibility Gap: the persistent distance between digitally generated design configurations and the manufacturing conditions required for industrial realisation. To address this gap, the study introduces the Reflective Digital Fitting (RDF) framework. RDF positions digital fitting as a recursive decision-making infrastructure where feasibility is progressively co-produced through continuous dialogue between design intent, material intelligence, computational modelling, and production knowledge. Rather than representing the final stage of virtual validation, digital fitting becomes the operational space in which creative experimentation and industrial viability converge through ongoing processes of systemic resource integration, adaptive learning, and value co-creation.

Digital Fitting as Service Infrastructure

Within S-D Logic, value is not contained in objects but emerges through interaction and co-creation among actors (Vargo & Lusch, 2016). In this sense, digital fitting is reframed as a service infrastructure that structures relational exchanges. Crucially, this infrastructure operates as an operant resource: it actively performs actions by reorganizing how knowledge is accessed, combined, and operationalized across design ecosystems (Barile, 2008; Golinelli et al., 2010). In the accessory design context, this infrastructure becomes a mechanism for integrating dispersed knowledge systems: material properties, manufacturing constraints, technical expertise, and design intent. Decision-making becomes continuously informed by infrastructural feedback loops rather than isolated creative acts. This configuration resonates with systemic views of service ecosystems where value emerges from recursive interactions among viable systems rather than linear production chains (Piciocchi et al., 2011; Saviano et al., 2010).

Digital Twin as Dynamic Relational Infrastructure

The digital twin is not conceptualized as a static digital replica, but as a dynamic relational infrastructure capable of synchronizing heterogeneous dimensions of design and production: geometric configuration, material behaviour, mechanical resistance, and industrial feasibility. From an S-D Logic perspective, the digital twin operates as an operant configuration of resources rather than a passive operand model, actively shaping design decisions through continuous feedback loops (Vargo & Lusch, 2008). Unlike conventional simulation systems, which isolate parameters, the proposed

digital twin propagates changes across interdependent layers, enabling Early-Stage Industrial Coupling—the progressive alignment between conceptual design decisions and manufacturing constraints before physical prototyping occurs (Casciani et al., 2022).

Conceptual Validation

The Reflective Digital Fitting framework is validated conceptually through the convergence of the theoretical perspectives integrated throughout this paper and their consistency with established accessory development practices. Rather than measuring technological performance, validation focuses on the internal coherence of the framework and its capacity to explain the relationships between design intent, material intelligence, manufacturing knowledge, and collaborative decision-making across representative accessory development scenarios.

Actor-To-Actor Ecosystem and Distributed Agency

The framework adopts an actor-to-actor logic in which agency is distributed across a heterogeneous ecosystem of human and non-human entities. Designers, suppliers, material systems, computational models, and manufacturing technologies all participate in the co-production of design outcomes (Spohrer & Maglio, 2010). Within this ecosystem, computational systems operate as active mediators of possibility: they define constraints, simulate structural behaviours, and generate predictive feedback that influences decision-making (Särmäkari & Vänskä, 2022; Tepe & Koohnavard, 2023).

Resource Liquefaction, Knowledge Integration, and Global Scale Production

A central mechanism of the framework is resource liquefaction, defined as the transformation of fragmented technical, material, and industrial knowledge into computationally operational forms (Barile & Polese, 2010). In accessory design, critical knowledge is dispersed across suppliers, manufacturers, technical experts, and designers. Through resource liquefaction, this dispersed knowledge is translated into structured, interoperable datasets that can be activated within the digital fitting environment, enabling infrastructural readability—where material and industrial constraints become legible within design processes from the earliest conceptual stages (Golinelli et al., 2012). To illustrate the impact of resource liquefaction on global-scale production, we present a mapping of a multi-continental workflow. When a design brand headquartered in Florence collaborates with a hardware specialist in Veneto, a leather supplier in Tuscany, and a manufacturing assembly plant in Dongguan (China), the physical distance creates massive temporal frictions and logistical delays (Repenning, 2024). Under a traditional workflow, multiple rounds of physical samples must be shipped across continents for mechanical and aesthetic validation, resulting in weeks of delay, high costs, and a substantial carbon footprint. By liquefying material data (such as

leather tensile strength, stitch-line friction, metal casting tolerances, and buckle lock resistance) and integrating them into the relational digital twin, the actors can conduct virtual fitting sessions. A mechanical clash or tolerance misalignment between the metal clasp and the leather flap is identified and resolved digitally in minutes.

This drastically reduces multi-continental physical sampling rounds, shrinking the prototyping lead time from 12 weeks to less than 3 weeks, and eliminating air transport emissions, thus demonstrating how global scalability and resource efficiency can coexist through infrastructural coordination.

Systemic Implications: Reconfiguring Design Complexity

The framework suggests that digital fitting does not reduce complexity but redistributes it across sociotechnical layers. Complexity moves away from physical prototyping and is relocated within computational infrastructures, data governance systems, and relational coordination mechanisms (Vargo & Lusch, 2016; Bassano et al., 2017). This redistribution affects design temporality, decision-making structures, sustainability outcomes, and knowledge organization. Importantly, it introduces a shift in design epistemology: feasibility is no longer tested at the end of the process but gradually constructed within the design environment itself (Wulff & Gustafsson, 2026).

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

The central limitation of current digital fashion systems lies not in computational power or visual fidelity, but in the disconnect between digital design and manufacturing knowledge.

The framework proposed in this paper emerges from the combined interpretation of the literature reviewed, the relational knowledge model developed throughout the conceptual framework, and practice-informed reflections on accessory development processes. This analytical progression provides the conceptual evidence supporting the identification of knowledge fragmentation as the primary challenge addressed by Reflective Digital Fitting.

Virtual artefacts may appear complete while remaining difficult or impossible to realise physically, particularly in accessory design, where minor geometric or material variations can have immediate functional consequences. Unlike apparel, accessories operate within tightly constrained mechanical systems in which aesthetic decisions are inseparable from structural and engineering requirements. Digital fitting should therefore be understood not merely as a visualisation or simulation technology, but as an infrastructural layer that incorporates production intelligence from the earliest stages of design, reflecting the broader shift towards integrated digital ecosystems connecting design, communication, and production (Capurro et al., 2026; Russo & Bassano, 2026; Russo et al., 2026). Because components such as hinges, clasps, and joints are intrinsically tied to manufacturing logic, their design simultaneously affects assembly and material performance. A Digital Twin can integrate these dimensions within a shared operational environment, incorporating production constraints, material behaviour, and

supplier knowledge into the workflow and making validation continuous rather than deferred to physical prototyping.

The contribution of this study is primarily conceptual and should be interpreted within that scope. The proposed Reflective Digital Fitting framework offers an interpretative model for integrating manufacturing knowledge into collaborative digital fitting processes rather than an empirically tested Digital Twin solution. Consequently, the paper does not evaluate quantitative performance indicators or industrial implementation outcomes. Future research should examine the framework through industrial case studies, collaborative accessory design projects, and Digital Twin applications capable of assessing prototyping efficiency, manufacturing coordination, and resource optimisation in operational settings.

Upcoming research should test the framework in industrial settings, focusing on interoperable systems that translate manufacturing data into design intelligence, AI models capable of anticipating production outcomes, and governance mechanisms addressing transparency, access, and epistemic equity within proprietary digital infrastructures. The contribution of digital fitting lies not in generating increasingly realistic representations, but in reorganising how design knowledge is produced and mobilised. In accessory design, bringing manufacturing intelligence into the creative process narrows the gap between design intent and production feasibility while preserving iterative exploration. More broadly, visual coherence in virtual space is insufficient without industrial plausibility: meaningful digital innovation requires continuous dialogue between creative possibilities and material consequences.

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