Designing Fashion Transitions: Toward Sustainable, Circular and Digital Futures

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Abstract
The fashion industry is undergoing a major transformation driven by emerging regulations and technologies that enhance transparency, accountability, and lifecycle monitoring. These developments open opportunities for circularity, traceability, and material innovation while reshaping design and manufacturing toward more sustainable practices. This study examines the role of design as a methodological tool supporting the transition to a circular and sustainable fashion ecosystem. It explores data-informed and generative design strategies that enable digital interoperability for mass personalization, and inclusive garment development. The research investigates hybrid practices that merge non-standard fabrication technologies with traditional craftsmanship, aligning with Industry 5.0 principles of human-centric production. By framing fashion as both a cultural practice and a complex industrial system, the study highlights design as a key transformative driver requiring cross-disciplinary collaboration, offering theoretical and practical insights for stakeholders navigating the shift toward a sustainable, digitally enabled fashion ecosystem.

Keywords
Fashion-tech,
Digital transition,
Green transition,
Circularity,
Augmented Craftsmanship

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INTRODUCTION

DIGITAL AND CIRCULAR TRANSITION CHALLENGES IN THE FASHION, TEXTILE, AND CLOTHING INDUSTRIES

The fashion, textile, and clothing (FTC) sector faces mounting environmental pressures, as excessive resource consumption and chronic overproduction continue to generate systemic overstock, waste accumulation, and heightened ecological impacts (Charter et al., 2024; Hejlova et al., 2025). Despite the sector's significant contribution to global emissions, water use, and material depletion, progress toward circularity remains limited, hindered by insufficient traceability and the lack of end-to-end visibility across supply chains (Ellen MacArthur Foundation, 2017). Recent EU policies, such as the Ecodesign for Sustainable Products Regulation (ESPR) and the introduction of the Digital Product Passport (DPP), aim to improve material transparency, waste accountability, and circular resource flows, yet their effective implementation in textile and fashion value chains is still at an early stage (European Commission, 2024; European Environment Agency, 2022). Companies are increasingly required to adopt sustainable and circular business models by enhancing durability, reparability, recyclability, and material transparency across product lifecycles, a shift that can be significantly supported by Industry 4.0 (I4.0) technologies that improve transparency, traceability, material- and waste-flow management. However, the persistent lack of interoperable digital solutions continues to hinder seamless communication, collaborative workflows, and data exchange across suppliers, designers, manufacturers, logistics, and recyclers, reinforcing operational inefficiencies and limiting lifecycle visibility and circular coordination (Bertola & Teunissen, 2018; Transition Pathway for Textiles Ecosystem, 2023; SBS & SMEunited, 2021).
Although the EU has defined an ambitious digital transformation agenda to build a secure, human-centric, and competitive economy by 2030 (European Commission, 2023a), and is actively supporting industry through improved financial mechanisms and initiatives aimed at enhancing digital competencies and the adoption of I4.0 technologies (European Commission, 2025; European Commission, 2024a), the FTC sector still struggles to translate this vision into a systemic change. The industry's digital and green transition remains hindered by deeply rooted structural, dimensional, and economic constraints. The siloed configuration of FTC supply and value chain, compounded by the dominance of micro, small, and medium enterprises with externalized production, outdated infrastructures, and limited financial resources, constrains investment in research, innovation, and shared infrastructures (European Commission, 2023; Euratex, 2023; RISE-SME, 2025). In addition, persistent socio-cultural barriers derived by strong craft tradition but a pronounced digital skills gap further restrict the sector's capacity to adopt advanced technologies (EU Strategy for Sustainable and Circular Textiles, 2022; Terziev et al., 2023; Cedefop, 2022). In the meantime, FTC workforce approaching retirement and difficulties in attracting younger talent is heightening the urgency for knowledge transfer of digital and sustainable competencies (Euratex, 2023).

DESIGN-DRIVEN INNOVATION OF THE PROCESSES FOR SUSTAINABLE AND CIRCULAR FTC

In the context of the green and digital transformation of the FTC industries, design assumes a pivotal role, given that roughly 80% of a fashion product's environmental impact is determined at the design stage, from material selection to production processes, durability, recyclability, and end-of-life outcomes (European Commission, 2020; Niinimäki et al., 2020). Yet design and production are often managed by many different companies, with limited early-stage collaboration, constraining knowledge sharing, workflow alignment, and the adoption of advanced digital technologies for achieving more sustainable solutions. In this paper we advocate that, adopting a design-driven perspective not only on products but also on processes and systems offers a strategical yet creative approach to systematically map and understand information flows, data, and tools across the supply chain, integrate diverse knowledge held by designers, manufacturers, and other stakeholders, while reinventing existing workflows around new goals, user experiences (both of consumers and fashion operators), and emerging value proposition. This perspective examines how changes in processes, enabled by I4.0 technologies, could reshape the configuration of supply and value chain, preserving the human and socio-technical dimension, ensuring workers remain central even in cyberphysical, highly automated systems, while enabling sustainable, circular, and flexible process innovation (Casciani & D'Itria, 2024; Dan & Østergaard, 2021). Early-stage process mapping, workflow simulation, and tool interoperability improve decision-making, reduce redundancies, and foster co-evolution of technological adoption and human expertise. In this way, design becomes not only a creative activity but a strategic lever for systemic transition, operational innovation, resilience, and environmental responsibility (Sevaldson, 2018; Baskerville et al., 2018). Applying this lens in the FTC context, especially when combining traditional craftsmanship, hybrid fabrication technologies, digital design, and circular economy (CE) principles, creates opportunities for transformative changes at the systemic level. A systemic and data-informed design approach can guide the transition from linear, fragmented supply chains to integrated, circular, and responsible fashion production ecosystems. By situating design of processes at the driver of innovation strategies and production planning toward sustainability, this paper introduces the project FashionTech Design for Circularity (FasT4C), that exemplify how digital and data-enabled workflows can reshape traditional practices, address socio-cultural, operational, and technological barriers, and redefine relationships between FTC stakeholders, enabling a holistic, human-centered, and sustainable transformation of the entire FTC ecosystem.

FASHION-TECH DESIGN FOR CIRCULARITY AND SUSTAINABILITY

The FasT4C project aim to promote sustainability and circularity in the FTC sector supported by the I4.0 technologies through a design-driven approach that spans the entire supply and value chain, framing digital and green (twin) transitions as interconnected opportunities to redesign processes from design to end-of-life toward a more sustainable and human-centered future (Floridi, 2020). A circular model for the whole FTC eco-system transformation emerges **Fig.1**, aligning with Industry 5.0 (I5.0) principles, thus promoting human-centered processes, co-creation between designers, operators, and machines, enhanced coordination, transparency, and inclusivity, while integrating CE strategies and the 9R paradigm (Potting et al., 2017).

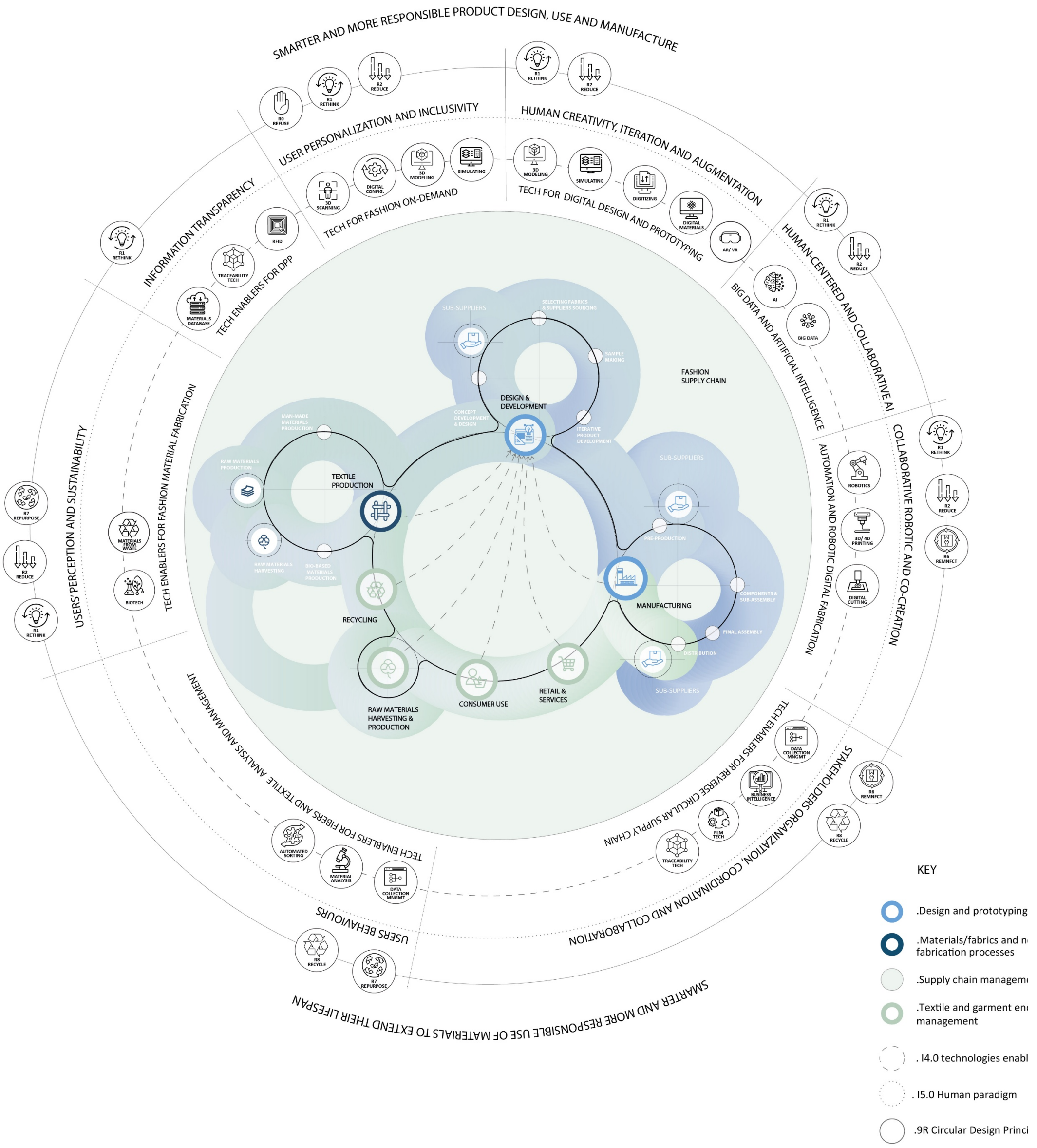

Fig. 1
FasT4C Model: a design-driven perspective describing synergistic twin transition (green and digital) for the FTC sector. The upper blue section focuses on responsible design and manufacturing boosted by digital technologies. The lower green section focuses on intelligent material use and recycling (Credits: Bertola, Casciani, D'Itria, 2024)

The lower green section of the model focuses on intelligent and sustainable material use, aiming to extend product lifespans through material monitoring, analysis, and recycling via technologies that allow reverse circular supply-chain thanks to data integration at the product lifecycle management level, and materials, textiles and products traceability via DPP implementation, along with the use of non-standard technologies allowing materials analysis, recycling and remanufacturing. Rethinking, remanufacturing, recycling, and recovering are the strategies through which materials are handled as new resources to be manipulated with new approaches at the design and fabrication stages.
In the upper blue section of the model, the emphasis is on responsible fashion design and manufacturing, enhanced through the integration of digital technologies for fashion mass personalization, and on-demand digital prototyping/fabrication through automation, collaborative robotics and non-

standard fabrication. Here, rethinking, reducing, refusing, and eliminating waste happens early at the design stages, through waste-free clothing prototyping and manufacturing processes, design for disassembly the garment at the end of life, and through personalized and customized on-demand approaches, encouraging a more responsible and demand driven production and consumption system. The blue section of the FasT4C model highlights the need for digital and data-driven approaches in design, prototyping, and manufacturing to address three interrelated challenges in the FTC sector: (i) limitations of conventional ready-to-wear design models in meeting diverse consumer needs, (ii) inefficiencies and overproduction of the ready-to-wear manufacturing model, and (iii) the erosion of traditional artisanal skills.

First, conventional mass-production models are characterized by overproduction, inaccurate demand forecasting, and standardized workflows that generate significant environmental waste and limit responsiveness to market fluctuations (World Economic Forum, 2020; Tang, 2023). Current approaches rely heavily on standardized sizing to maximize efficiency, which constrains inclusivity and contributes to consumer dissatisfaction and body image concerns (Haines & Lee, 2022; Cai et al., 2021). Research gaps exist in the development of parametric, customer-centric, and demand-responsive design and production approaches that can reduce waste, improve inventory strategies, and enable more adaptive, personalized garments (Guo & Istock, 2022; Jacobs, 2006; Nobile & Cantoni, 2023).

Second, the limitations in design and ready-to-wear manufacturing are compounded by the lack of integration between digital technologies and human-centered workflows. While automation and digital fabrication could support on-demand, flexible production, traditional digital tools often fail to fully interface with complex textile handling, hybrid analog-digital operations, and collaborative human-machine processes. There is an urgent need for research into non-standard fabrication technologies applied in the FTC, hybrid production workflows, and scalable micro-factory 4.0 models capable of efficient, customizable, and locally responsive manufacturing (Ugur Yavuz, 2020; Ciccarelli et al., 2024; Li et al., 2024; Nix & Sprecher, 2023; Chen et al., 2022). Such approaches could sustain new European models of hybrid digital craftsmanship while mitigating the third challenge: the projected decline of FTC artisanal skills. In fact, by 2030, globalized production, and outsourcing threaten traditional craftsmanship, whose tacit knowledge is recognized as Intangible Cultural Heritage but is expected to rapidly decline (UNESCO, 2003; ETP, 2016; 2022; 2024). Research gaps remain in methods to digitize and preserve tacit craft knowledge, integrate human expertise with I4.0 technologies, and train future artisans while maintaining socio-technical integrity, ensuring that customization, quality, and cultural value are retained in hybrid production systems (Brown & Vacca, 2022; Casciani & Vandi, 2022; Burden et al., 2020; Casciani & Chkanikova, 2023; Cedefop, 2022).

RESEARCH SCOPE AND METHODOLOGY

In this paper, we address three interconnected gaps of the contemporary FTC design and production processes: the absence of inclusive, data-driven tools for mass personalization; limited knowledge on integrating non-standard fabrication within hybrid human–machine workflows; and the lack of systematic methods for operationalizing artisanal expertise within emerging

I4.0/I5.0 systems. These challenges, rooted in rigid mass-production models, standardized sizing, insufficient digital integration, and the decline of craft skills, inform a unified research agenda focused on design-driven process innovation for sustainable, human-centered, and circular fashion ecosystems. In the blue part of the model, FasT4C project investigates how digital body data, biometric information, and human digital twins can be translated into accurate, parametric, and automated workflows for scalable mass personalization. It further examines how hybrid production systems, combining additive manufacturing, collaborative robotics, and augmented craftsmanship, can overcome material and operational constraints in fashion and textile fabrication. In parallel, it explores how new digitally driven workflows can be modelled, validated, and assessed for technical feasibility, social acceptance, and manufacturability within real industrial contexts.

To address these questions, the project applies a design of the process methodology that operates across multiple levels of the FTC ecosystem. While FasT4C aims to achieve a comprehensive understanding of the structures, relationships, actors, flows, and interdependencies at a macro level, providing the strategic foundation for FTC twin transition, at the meso and micro level, it focuses on workflows, protocols, stakeholder roles, interactions, tools, and practices. Therefore, this multi-level approach applies a design of the process's methodology for the two complementary research pilots: Digital Body and Generative Design for Mass Personalization, and Fashion Augmented Craftsmanship and Non-Standard Fabrication. Both pilots are implemented within the Circular Fashion Tech Lab, an interdisciplinary, networked research infrastructure that connects HEIs, students, and industry partners to support circular transitions across the FTC value chain. The methodological framework unfolds through four iterative phases: modelling existing workflows; conducting a technological survey and capability assessment; simulating and prototyping new workflows applying research-through-design experimentation; and implementing and evaluating redesigned processes to expose limitations, identify enabling tools, develop supportive materials.

Each pilot integrates a triple readiness assessment to ensure real-world feasibility: Social Readiness Level (user acceptance, literacy, and trust) (TRL), Technological Readiness Level (maturity and interoperability of tools) (SRL), and Manufacturing Readiness Level (organizational and workflow adaptations for scaling) (MRL). This combined evaluation ensures that proposed innovations are not only technically sound but also socially adoptable and industrially implementable.

PILOTING DIGITAL DATA-DRIVEN DESIGN IN THE ERA OF FASHION 5.0

THE DIGITAL BODY AND GENERATIVE DESIGN FOR FASHION MASS PERSONALIZATION

Redefining fashion design through computational and digital tools.
This pilot investigated how computational and digital fashion, supported by biometric data, 3D body scanning, human digital twins, and parametric modelling, can reshape garment design and production by enabling inclusive, automated, and highly customizable workflows. Responding to current debates on customer-centric fashion systems and the transition from mass production to mass personalization (Nobile & Cantoni, 2023), the pilot challenges the traditional ready-to-wear paradigm by introducing an

integrated digital pipeline that replaces static size-based logics with dynamic, data-driven modelling. This pipeline builds on: digital body acquisition to capture individual morphologies; parametric generation of sewing patterns derived from biometric inputs; virtual simulation to reduce reliance on physical sampling; and hybrid digital–physical manufacturing to support made-to-measure, on-demand production systems. Through this approach, digital technologies become more than instruments of efficiency: they act as enblers for reshaping the relationships between the body, design intentions, production capabilities, and user experience, prompting the FTC ecosystem to reconsider professional roles, workflow structures, and interactions between upstream and downstream actors in pursuit of more inclusive, responsible, and sustainable design and production models. The investigation acknowledges that the adoption of such technologies necessitates not merely the optimization but the fundamental redesign of processes which introduces new organisational arrangements, competences, and decision-making structures that cannot be absorbed into existing systems without a strategic, process-oriented design methodology.

A design of the processes methodology for fashion mass personalization. The pilot conceptualizes design of the processes as both a methodological and epistemic framework that highlights the socio-technical dimension of innovation, ensuring that technological advancements remain human-centred and that designers, pattern makers, and manufacturing professionals retain agency within increasingly automated, cyber-physical design and production environments. The research activities were structured around four interconnected phases of empirical experimentation, comparative technological assessment, research through design, and socio-technical analysis. The first phase validated digital body acquisition technologies by comparing cabin body scanners, and app-based systems with manual methods, assessing accuracy, TRL, interoperability, and user perception: this revealed persistent misalignments between digital outputs and traditional measurements practices. The second phase developed and tested a new parametric measurement-to-pattern workflow, confirming its feasibility through virtual and physical prototyping but showing that high-TRL digital tools still lack interoperability for seamless pipelines. The third phase examined human factors, identifying varying levels of trust in scanning technologies and significant interdisciplinary skill gaps among fashion operators, underscoring that digital transformation relies as much on socio-cultural and educational readiness as on technical maturity. A final phase focused on capacity building, producing an open-source educational and professional toolkit, including supporting adoption across the FTC ecosystem. The interdisciplinary research merged mechanical and biomedical engineering contributing to ergonomic parameters, measurement validity, and accuracy thresholds for digital body acquisition (POLIMI DMEC), fashion design and pattern-making ensuring the translation of biometric data into scalable pattern logics while articulating and validating the workflow to ensure processes coherence and replicability (POLIMI DESIGN); and psychology of decision making providing insights into user perception, SRL trust, and behavioural acceptance (UNIPD DPSS).

Outcomes, systemic insights, and implications for mass personalization. This pilot produced several concrete results that validate the feasibility and potential of integrating computational fashion, biometric data, and automated parametric design within a coherent workflow for FTC mass personalization. The Open Toolkit stands as a central outcome, offering a structured and accessible collection of resources that operationalize the methodology and support widespread adoption. Its workflow documentation clarifies the interdependencies among tools, identifies limitations and opportunities, and provides a stable basis for future industrial integration, **Fig.2**.

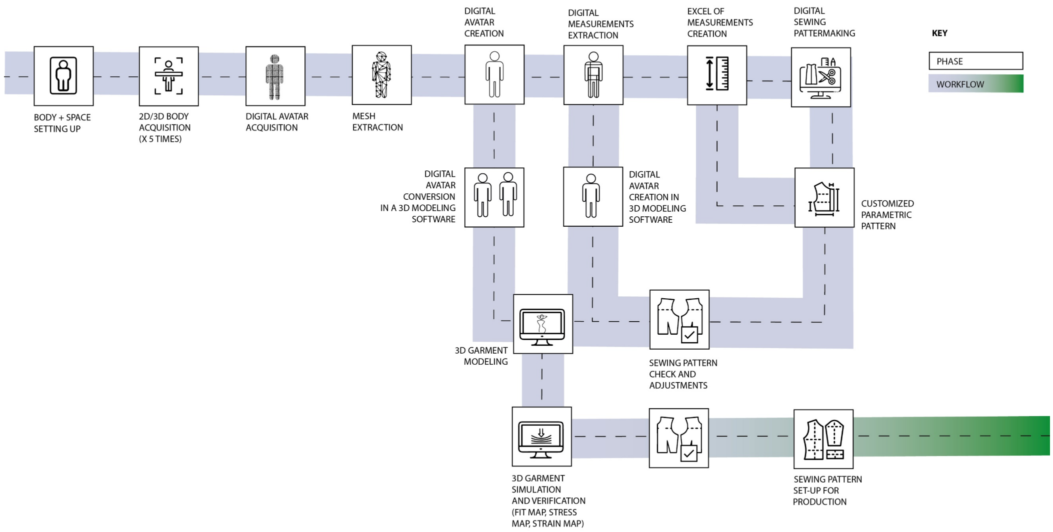

Fig. 2
Digital workflow from body scanning for digital avatar and measurements acquisition to personalized pattern design (Credits: Bertola, Casciani, D'Itria, 2024).

The instructional video tutorials function as didactic material for both academic settings and professional upskilling, while the technical guidelines ensure measurement of coherence and mapping between digital and physical garment construction. A basic database of parametric sewing patterns and validated digital/physical prototypes demonstrate the practical applicability of the workflow and the capacity of parametric modelling to respond dynamically to different bodies. The results reveal both transformative potential and significant systemic challenges. While the integration of digital body acquisition, automated pattern generation, and virtual simulation enhances the precision, inclusivity, and responsiveness of garment design, their implementation exposes frictions within existing organizational and cultural structures. Despite high TRLs for individual technologies, the absence of fully integrated, interoperable pipelines inhibits large-scale adoption. The experimentation demonstrated that digital tools disrupt conventional workflow sequences, requiring redefinition of roles, responsibilities, and communication protocols across the supply chain. For instance, pattern makers confront new relationships between digital measurement outputs and traditional expertise; designers must adapt to parametric and algorithmic logics; and production managers must negotiate new forms of data exchange across suppliers, manufacturers, and distributors while disrupting production cycles. Furthermore, the research shows that digital personalization cannot be achieved without developing new interdisciplinary competencies and enhancing better communication flows across stakeholders. The need for hybrid profiles such as design-technologists capable of navigating data modelling, ergonomics, pattern logic, and system integration, becomes a structural condition for scaling digitally driven made-to-measure processes. The findings thus support the argument that digital transformation in fashion is a process-design problem as much as a technological one: successful integration requires deliberate reshaping of processes, supported by training, cultural adaptation, and systemic coordination rather than isolated technological adoption. Finally, from a strategic perspective, the project demonstrates that the design of the processes can align technological capabilities with demand-driven, service-oriented production models by enabling modularity, real-time information exchange, and agile manufacturing (Wang et al., 2017). The systemic mapping of the supply chain highlights that mass personalization can be economically viable and scalable when supported by integrated customer and supply-chain intelligence, robust data governance, and coordinated design-to-production workflows (Ruzive & Tsang, 2023).

FASHION AUGMENTED CRAFTSMANSHIP AND NON-STANDARD FABRICATION

Potential and limitations of additive manufacturing and collaborative robotics for FTC augmented craftmanship
This pilot investigated how additive manufacturing (AM), collaborative robotic (CR) and non-standard fabrication can be systematically integrated into FTC through a design-driven, process-oriented methodology. Although AM has reached high TRL in sectors such as product design and industrial prototyping, its application to garments, textile-like structures, and hybrid craft processes remains limited. The preliminary research assessment, grounded in case studies, best practices, and comparative testing of hardware and software tools, revealed both the strategic potential and the persistent constraints of AM in fashion. On the one hand, digital modeling and fabrication techniques offer unprecedented advantages in the mass production of complex geometries, significantly reducing time, material waste, and cost. They also enable the re-materialization of garments, accessories, trims, and finishing elements through highly controlled, automated fabrication paths. On the other hand, fundamental barriers continue to restrict large-scale adoption: material properties failing to achieve essential apparel requirements such as softness, drape, breathability, and comfort; interoperability challenges between digital garment design tools and AM systems; and a lack of optimization of existing hardware and software for the dimensional, mechanical, and aesthetic feature required by FTC applications. Similarly, workflow fragmentation and insufficient integration between CAD, slicing software, and digital fabrication systems limit the scalability of AM within FTC production environments. The pilot research therefore situates itself within these gaps, aiming to understand how AM can be adapted, reconfigured, and hybridized with analog craftsmanship to expand material and performative possibilities while supporting more sustainable, circular production scenarios.

A design of the processes methodology for hybrid human-machine fabrication
The pilot project applied a comprehensive design of the processes methodology for integrating AM with fashion craftsmanship, articulated across iterative and interdisciplinary experimentations. The goal was not only to optimize and create new tools but to redesign the entire workflow through which garments and accessories are conceived, materialised, and validated. The methodology combines fashion and pattern-making design (POLIMI DESIGN), textile and material engineering (POLIMI DCMIC – POLITO DIATI), mechanical engineering and robotics (POLIMI DMEC), and human-factor disciplines. This integration supports the development of collaborative, hybrid

operations in which digital fabrication enhances the FTC artisanal expertise. The team conducted extensive testing of analogue and digital processes to evaluate compatibility, efficiency, and aesthetic potential. This included experiments in AM on textile substrates, creation of textile-like structures through hybrid analog–digital approaches, and the development of garment accessories such as buttons, buckles, inserts, and decorative elements. A collaborative robotic demonstrator was established within the Circular Fashion-Tech Lab to explore human–machine interaction in non-standard fabrication processes on planar and tridimensional surfaces. Material sampling activities broadened the range of usable filaments, integrating traditional, unconventional, and recycled materials into bio-based compounds to address sustainability goals. The derived proof of process (PoP) validated these workflows by assessing their technical feasibility, functional performance, and alignment with traditional craft logic, exploring synergies between automation and manual operations. Process design enabled also the mapping of operational constraints, identification of skill requirements, evaluation of interoperability gaps, and development of strategies for sustainable and on-demand hybrid manufacturing systems.

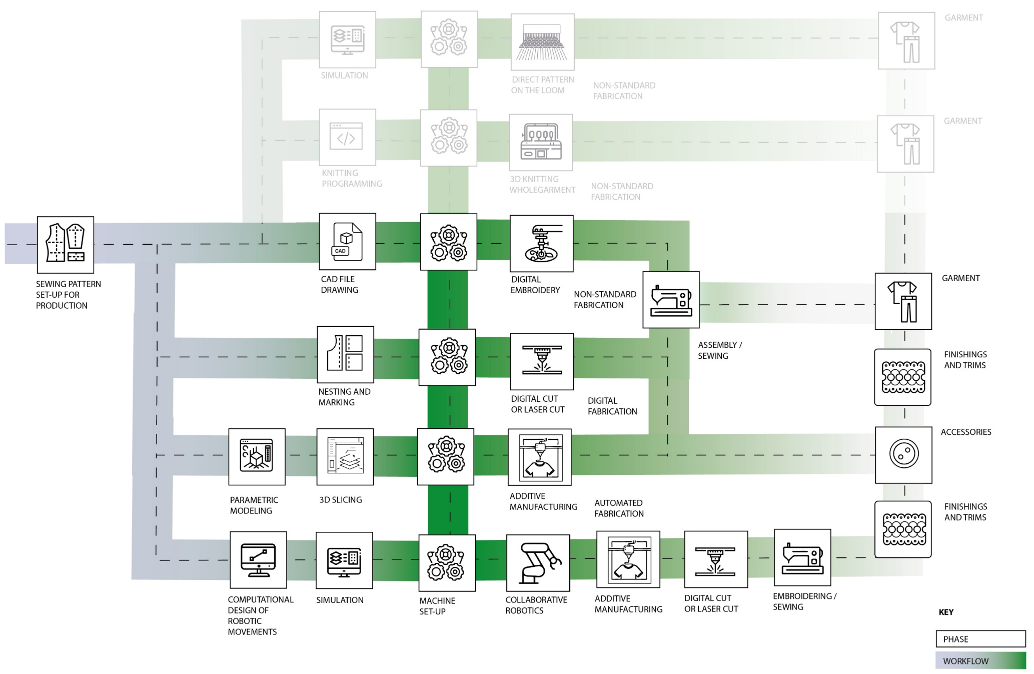

Fig. 3
Digital to physical walkthrough of technologies for re-materialization of garments, finishing and trims, and accessories (Credits: Bertola, Casciani, D'Itria, 2024).

OUTPUTS, SOCIO CULTURAL INSIGHTS, AND CAPACITY BUILDING

A key outcome of this pilot is the development of an Open Toolkit designed to facilitate the adoption of AM and hybrid fabrication within the fashion industry and educational ecosystem. The toolkit includes: (i) a design-oriented operational protocol for robotic arms in fashion and cross-sector applications **Fig. 3**; (ii) CAD and parametric modeling templates for constructing textile-like structures and garment components; (iii) source code and scripts enabling collaborative 3D printing of textile-like structures and 3D printing on fabrics; (iv) a material dataset optimising printing parameters for conventional, unconventional, and recycled filaments; and (v) a catalogue of real-world case studies illustrating prototypes, rematerialization workflows, and functionalization experiments. These resources support designers, students, researchers, and companies in testing, validating, and scaling AM workflows for accessories, trims, and textile-based applications. By connecting makers with innovative materials and fabrication strategies, the project addresses broader socio-cultural challenges such as skill erosion, technological fragmentation, and the integration of younger practitioners into craft-based domains (ETP, 2024). Also in this pilot, research findings indicate that digital transformation in fashion requires not only technological maturity but also cultural, educational, and organisational readiness. Designers must acquire skills in parametric modeling and robotic control, pattern makers must navigate digital workflows, and technicians must interpret fashion material behaviours and manage interoperability across tools. Process evaluations underscored the need for workflow transparency, tool reliability, and alignment between digital and craft expectations. Importantly, they highlight how hybrid human–machine operations can preserve and revitalise artisanal knowledge by enhancing precision, safety, and creative agency, contributing to sustainable and circular fashion practices by enabling on-demand production, reducing material waste, expanding repair and rematerialization strategies, and fostering new expressions of textile-based design.

CONCLUSIONS AND FUTURE RESEARCH

The FasT4C project demonstrates how the adoption of digital, computational, and hybrid fabrication technologies can fundamentally transform the fashion, textile, and clothing (FTC) sectors, fostering more inclusive, sustainable, and circular production models. Through its two pilots, Digital Body and Generative Design for Mass Personalization and Fashion Augmented Craftsmanship and Non-Standard Fabrication, the project illustrates that the integration of biometric data, human digital twins, parametric modeling, AM, and collaborative robotics enables the creation of highly personalized, on-demand garments. These interventions not only address the inefficiencies of traditional mass production but also mitigate the ongoing erosion of artisanal skills, embedding new technologies within structured, design-driven workflows that align with I5.0 principles and human-centered practices.
Central to this transformation is the adoption of a design-driven methodology that explicitly positions design as both a strategic and operational agent of change. FasT4C approaches the FTC ecosystem at multiple levels: at the macro level, system design frames the strategic vision by mapping the structures, relationships, actors, flows, and interdependencies that define the sector, thereby setting the conditions for sustainable, human-centered, and circular transformation. At the meso and micro levels, process design translates this strategic vision into actionable workflows, protocols, tools, and touchpoints while experimenting within the pilots, ensuring that systemic ambitions are rendered operational and measurable. In this way, process design functions as the operational infrastructure of system design, while system design provides the strategic orchestration that aligns vision, stakeholders, and technology. This dual approach positions design as both a methodological tool, guiding the practical implementation of workflows, and an epistemic instrument, producing new knowledge about the functioning, constraints, and potential of complex socio-technical systems.
In the context of the FTC sector, where supply chains are highly fragmented, networked, and multilocal, such a dual-level approach is essential. Systemic vision alone is insufficient without redesigned processes to render these visions operational, while process design without a system-level framework

risks misalignment. The interplay between system and process design thus allows FasT4C to bridge strategic ambitions with operational realities, translating abstract objectives into repeatable, scalable, and measurable workflows.

By leveraging interdisciplinary expertise spanning fashion design, pattern-making, textile and material engineering, mechanical engineering, robotics, digital imaging, and human factors, FasT4C demonstrates how design can mediate between diverse knowledge domains, integrating them into coherent and scalable workflows. This approach supports the interoperability of digital and traditional craft practices while preserving the agency of designers, pattern makers, and technicians in increasingly automated and cyber-physical production systems. Iterative experimentation, tool benchmarking, and parametric and AM workflow testing have revealed both substantial opportunities and persistent challenges, including interoperability gaps, skill mismatches, and tensions between traditional craft practices and digital approaches. To address these barriers, the project has developed open-access resources, including CAD templates, robotic protocols, material datasets, and educational toolkits, which promote knowledge sharing, professional upskilling, and broader adoption across academic, industrial, and artisanal contexts.

The Circular Fashion Tech Lab serves as the central platform for this work, functioning simultaneously as a hub for interdisciplinary research and experimentation and as an educational environment for cultivating the next generation of hybrid designers. Within the Lab, students, researchers, and practitioners collaboratively co-create, test, and refine digital and hybrid workflows in real-world, circular fashion contexts. By connecting technological experimentation with hands-on learning, the Lab will operationalize the FasT4C vision, equipping designers to navigate complex hybrid production systems and engaging with FTC industries to strategically and systematically operate their twin transformation in a real scalable context.

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