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Abstract
In the context of the digital transition of the Italian textile industry, this paper explores how design can act as a mediator between emerging technologies, sustainable practices, and sector-specific knowledge. The research adopts the perspective of the Transitional Industrial Designer (TID), a figure capable of integrating vertical technical expertise, adaptability to change, interdisciplinary collaboration, and systemic thinking.
Through a practice-based experimentation on the virtualization of textile materials, the project investigates the role of design in enabling accessible, scalable, and collaborative processes. The focus is not on technological solutions alone, but on the design practices that mediate complexity and facilitate the adoption of immersive and digital tools across different stakeholders. Structured as an interconnected system rather than a linear workflow, the experimentation combines acquisition, interaction, and archiving of virtual materials to support sustainable, distributed design practices. The outcomes highlight the potential of anticipatory design approaches in activating new modes of interaction with materiality and in supporting the circular transition of Made in Italy industries. Ultimately, the study offers a methodological reflection on how designers can responsibly navigate digital complexity

Keywords
Textiles
Transitional Industrial Designer
Open-source Workflows
Textile Heritage
Extended Reality

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INTRODUCTION

Representation tools have always been a fundamental component of design, shaping the development and evolution of projects over time. With the advent of digital technologies and software, the influence of these tools has become increasingly pervasive. As Manovich (2013) argues in *Software Takes Command*, digitality now conditions designers' choices, as software itself becomes embedded within both the ideation and representation phases of the design process.

The context described by Manovich (2013) can be seen as a precursor to the complexity we are currently experiencing—what appears to be a new technological revolution of similar magnitude to the birth of the internet. This transformation is driven by two major developments: the widespread adoption of Artificial Intelligence (AI) and the emergence of Extended Reality (XR) (Zannoni et al., 2022). While the integration of AI has already entered the market and is shaping multiple sectors, XR remains in its early stages, limited by bulky, costly, and technically immature hardware that is not yet accessible to a broad audience.

Within this evolving landscape, Meta's approach, following its acquisition of Oculus, stands out for offering a stable, affordable, and open ecosystem for XR development, potentially providing designers with a viable technological foundation for product and service innovation.

The immersive and virtual context thus emerges as a fertile ground for anticipatory research aimed at understanding how designers might engage with tools that augment human perception and reshape our vision. However, the lack of tactile feedback and physical response still confines many wearable XR devices to the domain of entertainment, rather than positioning them as tools for daily, professional design practice.

This project, presented as a low-TRL experimentation, seeks to investigate the long-term potential of immersive tools within remote co-design workflows, where materials are virtualized, and perceptual experiences are simulated. On the one hand, there is a need for open, affordable tools to capture haptic and visual material qualities; on the other, we require new hardware capable of rendering increasingly accurate tactile sensations.

The research is structured along two parallel yet interconnected lines: an applied stream—developed collaboratively with UNIBO and CNR—that has surpassed expected TRL levels by producing open-source tools; and a second stream focused on validating user experience through usability testing and the perceptual fidelity of haptically rendered surfaces.

These two strands represent complementary facets of the same objective: a new generation of tools enabling richer interactions between designers, materiality, and form.

THE TRANSITIONAL INDUSTRIAL DESIGNER AND THE DIGITAL TRANSFORMATION OF THE TEXTILE SECTOR

To design an accessible and feasible process within the production supply chain, it is essential to identify a figure capable of managing its intrinsic complexity. Contemporary industrial contexts are characterized by intertwined, multidisciplinary domains, involving multiple actors and both material and immaterial processes. In such scenarios, the designer must act as a mediator among the various stakeholders (Celaschi, 2008), adopt a

holistic approach across multiple project scales, and navigate the transitions toward future-oriented design models (Irwin, 2015).
The *Transitional Industrial Designer* (TID) (Zannoni et al., 2024) embodies the ability to apply anticipatory practices (Celaschi & Celi, 2015) in the transformation of social, economic, environmental, and production contexts, operating through an ecosystemic perspective that considers all material and immaterial elements as interconnected. The TID combines technical expertise, collaborative methods, and ethical-social sensitivity see **Fig. 1**, making this figure particularly suited to contexts in need of innovation and cooperation, often with limited resources.

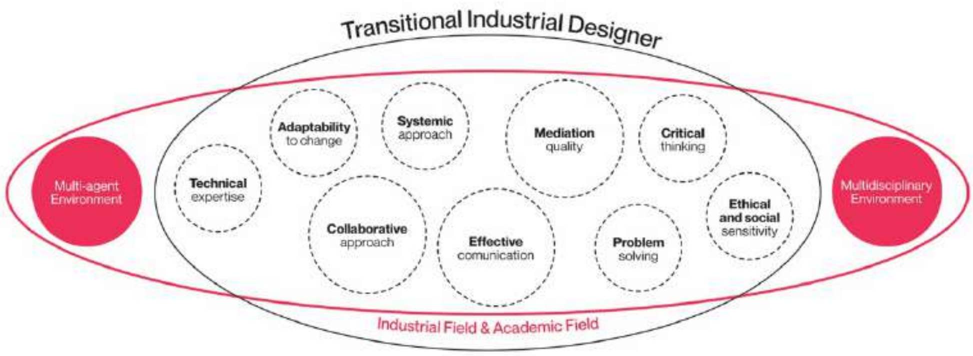

Fig. 1
Transition Industrial Designer Framework (Credits: Advanced Design Unit, 2024, from Zannoni et al., 2024).

This research proposes a reflection on the design practices and tools that the TID can implement within a specific project, aiming to highlight design approaches, models, and instruments for a sustainable, circular, and digital transition.
The research project investigates the opportunities arising from the integration of digitalization processes into textile materials, particularly within the fashion sector. This field is especially promising for two main reasons: first, digitalization in fashion design can contribute to a more sustainable and circular supply chain—fashion being the second most polluting industry globally (Ellen MacArthur Foundation, 2021); and second, it expands the sector's reach by enabling new products, markets, and professional profiles (Rosato & Calleo, 2023).
Virtual fashion can be developed across three main levels of digital technology application: product development and visualization, marketing and communication strategies, and the creation of digital-only garments and accessories (Särmäkari, 2021). Intervening in these areas can serve as a powerful lever to reduce environmental impact throughout the entire product life cycle—from design to production, communication, distribution, consumption, and disposal. The progressive digitalization of the prototyping process, through the acquisition of the fabric sample and the use of 3D textile modeling/rendering applications, plays a crucial role in evolving toward zero-waste production models, allowing designers to explore and anticipate the relationships between form, pattern development, and textile waste generation (McQuillan, 2020).
The increasingly structured dialogue between digital fashion and virtual environments has led to the emergence of new product categories conceived

and commercialized exclusively in digital form. Virtual garments and accessories are now created to be worn by avatars in video games or digital platforms, through original designs or collections from established brands (Gibson, 2021).
These are the guiding principles that shaped our experimental work, particularly focusing on tools that support the virtualization of the material selection process. The aim is to reduce the environmental impact of textile sample distribution (Vezzoli et al., 2022) and enable the creation of a shared platform for digital textile materials, facilitating remote prototyping and expanding access to emerging digital markets.
Such digitalization processes activate new ways of interacting with materiality, significantly influencing both the individual and collective experience of design.
Recent developments in textile design already demonstrate how digital tools reshape material decision-making, confirming Manovich's argument that digitalization influences designers' choices. Several projects integrate 3D weaving simulators, virtual looms, and physically based rendering engines to replicate the interplay of warp and weft, allowing designers to evaluate textile behavior before physical production. Tools such as Cloth component for Unity (Unity - Manual, s.d.) , which enables real-time simulation of fabric deformation and drape, allow designers to assess the structural behavior of textiles before physical prototyping. On the same way, Zero10AR demonstrates how digital garments can preserve the visual and volumetric qualities of woven materials within augmented reality experiences, expanding opportunities for experimentation and communication (ZERO10 AR & AI Solutions for Business | Virtual Try-On, s.d.). Otherwise, Vellum for Houdini provides a highly detailed physics-based simulation system capable of reproducing the interactions between warp, weft, and material properties, making it possible to model comfort, elasticity, and tactile expectations with increasing accuracy (Vellum, s.d.). These examples reveal that digital environments do not merely translate textiles into flat visual surfaces but increasingly capture the structural logic of weaving. Such approaches also underline the importance of clarifying the notion of texture, understood here as the perceptual outcome, both visual and haptic, of material composition and interlacement patterns. Integrating these references reinforces how digitalization engages deeply with the intrinsic materiality of textiles rather than abstracting it.

METHODOLOGY AND OBJECTIVES

The work presented here is situated within the framework of Digital Advanced Design for Made in Italy, which constitutes the shared foundation of the projects developed under the MICS partnership and specifically those clustered within Spoke 1. A distinctive feature of this cluster is the emphasis on design as a mediating discipline, a quality that permeates all the research initiatives emerging from this collective effort.
This paper focuses on the project *Advanced virtual tools for digital acquisition and visual/haptic XR interaction for the textile industry*, which exemplifies a shift in the designer's role—from traditional creative direction and product ideation to a more measured, technologically-informed, and responsible methodological stance.
From the early stages of the meta-research, it became evident that the excellence of the Made in Italy system, especially in the textile and furnishing

sectors, is largely rooted in industrial districts composed of highly specialized SMEs (small and medium enterprises). While these enterprises possess remarkable expertise, they often operate with limited resources. Thus, a key objective was to explore innovations that could support the entire sector, ensuring that the proposed tools were accessible not only in terms of time and cost but also in relation to users' technological literacy, often low in the intended target context.
Field research further revealed that the main barriers to the adoption of more digital and immersive approaches are both technical, due to the complexity of 3D model generation, and perceptual, as the ideation and evaluation processes in these industries remain closely tied to tactile sensitivity.
Within this framework, the virtualization of textile textures emerged as a particularly promising area of focus. This involves addressing both the need for high-quality visual fidelity and the capacity to reproduce textures through haptic feedback. Accordingly, a dedicated workflow was proposed for the digitization of textile samples, structured into three phases: acquisition and modeling, restitution through haptic interaction, and archiving. These were developed over the course of a 24-month period.
The adopted approach combined parallel yet coordinated development streams, enabled by a high level of communication among collaborators. It was also characterized by a strong experimental and practice-based component, which proved essential for evaluating the outcomes and identifying potential future implementations of the system.

TOOLS FOR A DIGITAL, CIRCULAR, AND SUSTAINABLE TRANSITION

The experimentation presented here takes place within a context of increasing interest in the accessible and sustainable digitalization of textile materials, with particular attention to their representation in virtual and collaborative design processes. The objective is to explore a set of tools and methodologies capable of translating physical textile samples into faithful and interactive digital counterparts, while maintaining low technological costs and ensuring high visual and tactile quality.
The experimental process is structured into three main phases, each designed to address the specific needs of different stakeholders within the textile value chain, from manufacturing companies to digital fashion professionals, researchers, and cultural institutions.

- Acquisition and modeling: A low-cost digitization pipeline is proposed, centered on the use of the SALA-Frame device, developed to optimize light positioning during photometric acquisition. The collected data are processed using open-source software such as RelightLab and Blender, with the aim of generating high-fidelity digital textures ready for integration into 3D environments.
- Real-time tactile interaction: The digital counterpart of the textile is integrated into an immersive environment developed with Unreal Engine, where users can experience realistic tactile simulation through the use of the WeArt haptic device. This phase explores the potential of multisensory interaction for collaborative design and remote material evaluation.
- Archiving: The final phase involves the development of a digital archive of virtualized textile materials, intended as a support tool for material

selection and design processes. The archive seeks to connect the technical dimension of the digitized samples with the relational dynamics of the supply chain, offering an immersive and interactive consultation system for various stakeholders.

Through the integration of customized hardware, open-source software, and immersive devices, this experimentation proposes a scalable and replicable design approach capable of addressing the challenges of sustainability, accessibility, and digital transition within the textile sector.
These tools are designed to be used at different stages of the design process. With regard to acquisition and modelling, they operate during the phase dedicated to representing the sample collection, a moment in which the company aims to disseminate, share, and showcase its products.
The other two tools, by contrast, are essential in the upstream phases of the process and support the designers of companies wishing to work with their textiles. Specifically, they intervene in the design and selection of materials, enabling the creation of a collaborative, distributed, remote, and immersive environment. The archive makes it possible to visualise a complex textile heritage connected to local enterprises and provides access to both the physical and digital properties of the materials made available by the companies.
Finally, the haptic visualisation modalities constitute valuable tools in the informed selection of materials, as they support an assessment that integrates technical data with a simulated sensory experience, as described in the contribution.

ACQUISITION AND MODELING

The methodology was designed to meet the needs of a diverse group of users, including textile companies seeking low-cost digitization tools, cultural institutions with limited budgets, and researchers requiring high-fidelity digital reproductions. The acquisition process can be applied in areas like game development, VFX, and product or interior design when high-fidelity digital reproduction of textures is essential. However, in some instances within these fields, less accurate but faster tools and methodologies might be chosen if they provide results deemed acceptable for the specific application.
To achieve these objectives, we adopted the photometric stereo technique as our acquisition strategy, which determines surface orientation by analyzing the way light is reflected from the surface (Woodham, 1978). To facilitate this in a low-cost manner, our workflow supports the use of a simple hand-held light source. While this approach is inexpensive, it introduces the challenge of precisely determining the light's position for each shot, —posing a procedural challenge for designers seeking to integrate open-source and low-cost processes within enterprise contexts. A possible solution involves placing reflective spheres in the frame and inferring the light's position from its specular highlights. However, this method requires significant manual work to identify the highlights and reduces the effective resolution of the sample by occupying frame space.

Fig. 2
The Shadow-Aided Light Alignment Frame (SALA-Frame) (Credits: 3D print and photo Gaeta B., SALA-Frame Foschi R., 2025).

To overcome these limitations and enhance both accessibility and accuracy, our research focused on developing a novel, affordable workflow centered around the Shadow-Aided Light Alignment Frame (SALA-Frame). The SALA-Frame **Fig. 2** is a custom-designed, 3D-printable hardware that enhances the accuracy of light sampling by using cones that cast shadows onto circular grids, enabling precise alignment of the light source without the necessity of a physical dome or reflective spheres. This design facilitates digitizing various materials with a controlled and calibrated lighting setup. Developing tools, tutorials, and support resources to enhance the learnability of a digital system is a fundamental process for ensuring a smooth and effective user experience, as well as for fostering a pleasant and meaningful interaction with the system.

The operator is intuitively guided to place the light source in a precise, predefined position by simply aligning the tips of the four shadows with the corresponding points on the grids (Foschi et al., 2024). This method maximizes the effective resolution of the sample area (typically 50x50mm with the standard SALA-Frame) and makes the preliminary processing of light positions nearly as accurate as using a predefined light dome. Empirical tests show the positioning accuracy is on the order of a few millimeters, which is more than sufficient for high-quality acquisition in this context (Foschi et al., 2024). Furthermore, by using a single light source, the problem of color and intensity variation between multiple lights is mitigated, contrary to what could happen when using a calibrated dome with multiple light sources. The comparison between the various digitization methods mentioned is synthesized in **Table 1**.

	DIY construction/preparation		Acquisition		Processing	
	Complexity	Time consumption	Complexity	Time consumption	Complexity	Time consumption
SALA-Frame	low	low	moderate	moderate	moderate	low
Dome	high	high	moderate	low	moderate	low
Reflective spheres	low	low	low	moderate	moderate/ high	moderate

	Rig/sample size ratio	Cost	Inaccuracy	Calibration complexity
SALA-Frame	moderate	low	low	low
Dome	high	high	low	high
Reflective spheres	low	low	moderate	moderate

Tab. 1
Comparative analysis of three acquisition methodologies: SALA-Frame, Dome, and Reflective Spheres. For all criteria presented in both tables, a 'Low' rating represents the most favorable outcome, while a 'High' rating indicates the least.

The resulting workflow is both cost-effective and versatile. The core hardware (SALA-Frame) can be produced on any consumer 3D printer (the majority of the designated users have access to a 3D printer,a FAB lab, oronline services), and the required equipment, a digital camera (or smartphone) on a tripod, a handheld light and a screen light, consists of items easy to acquire or usually already owned by institutions. The only specialized equipment that might require purchase is a color checker, which is substantially cheaper than professional material scanners. However, as an alternative, white balance can be calibrated prior to acquisition by illuminating a white surface with the same light source that will be used during the process. The subsequent processing of the captured images is managed by RelightLab, an open-source software (Ponchio et al., 2019; Cnr-Isti-Vclab/Relight: A RTI Library for Creating and Visualizing Reflectance Transformation Imaging, n.d.) that has been significantly enhanced to support this low-cost acquisition pipeline. RelightLab offers several advantages that contribute to the system's versatility, scalability, and reliability. Key among these is its user-friendly interface, which intuitively guides the user through the digitization process in chronological order using a series of tabs on the left-hand side of the screen. This interface simplifies crucial steps such as scaling the sample images and determining the precise position of light sources, also when reflective spheres are used instead of the SALA-Frame. This decision aimed to facilitate the tool's learnability, making it more accessible and intuitive for end users. The

software employs mathematical algorithms to accurately and reliably extract essential texture maps, including base color (albedo), normal maps, and height maps, directly from the acquired image set. This deterministic approach ensures that results are reproducible and consistent, providing a reliable alternative to AI-based methods, where outputs can vary even with identical inputs. While potentially slower than some automated AI solutions, this methodology guarantees robust and verifiable outcomes suitable for high-fidelity digital reproduction (Foschi et al., 2024).
The transformation of acquired image data into versatile and realistic virtual materials represents a critical subsequent stage, designed to be cost-effective, accessible, and intuitive, particularly for professionals in the textile and fashion industry who may not be rendering specialists. This phase bridges the gap between raw digital captures and their application with a strong emphasis on supporting sustainable practices by reducing the need for physical prototypes.
The cost-effectiveness of the post-processing workflow is primarily achieved through the strategic use of open-source software, with Blender (*Blender.Org - Home of the Blender Project - Free and Open 3D Creation Software*, n.d.) serving as the central platform for material set-up and rendering. While Blender offers a comprehensive suite of tools, certain specialized tasks, such as creating seamlessly tileable textures, are crucial for textile representation. Currently, this tiling process is managed using dedicated low-cost commercial software like PixPlant (*Tiling 3D Materials, Quickly*, n.d.), as this functionality is a planned future development for fuller integration within our primary open-source tool chain. The core texture maps, such as albedo (base color), normal, height/displacement, are generated by the RelightLab software from the acquisition phase. However, the accurate generation of all PBR (Physically Based Rendering) maps directly from acquisition remains an area of ongoing development. Specifically, roughness and metallic maps, which define a material's micro surface scattering and metallic properties respectively, are currently derived through a qualitative visual comparison with the physical fabric sample. This often involves editing the albedo map in image manipulation software or directly adjusting parameters within the 3D modeling environment (Zannoni et al., 2024).
A key objective of this project phase is to enhance the usability and intuitiveness of applying these PBR textures within Blender, specifically for users in the textile and fashion sectors who are not 3D experts. To address this, a custom Blender addon **Fig. 3** is under development.

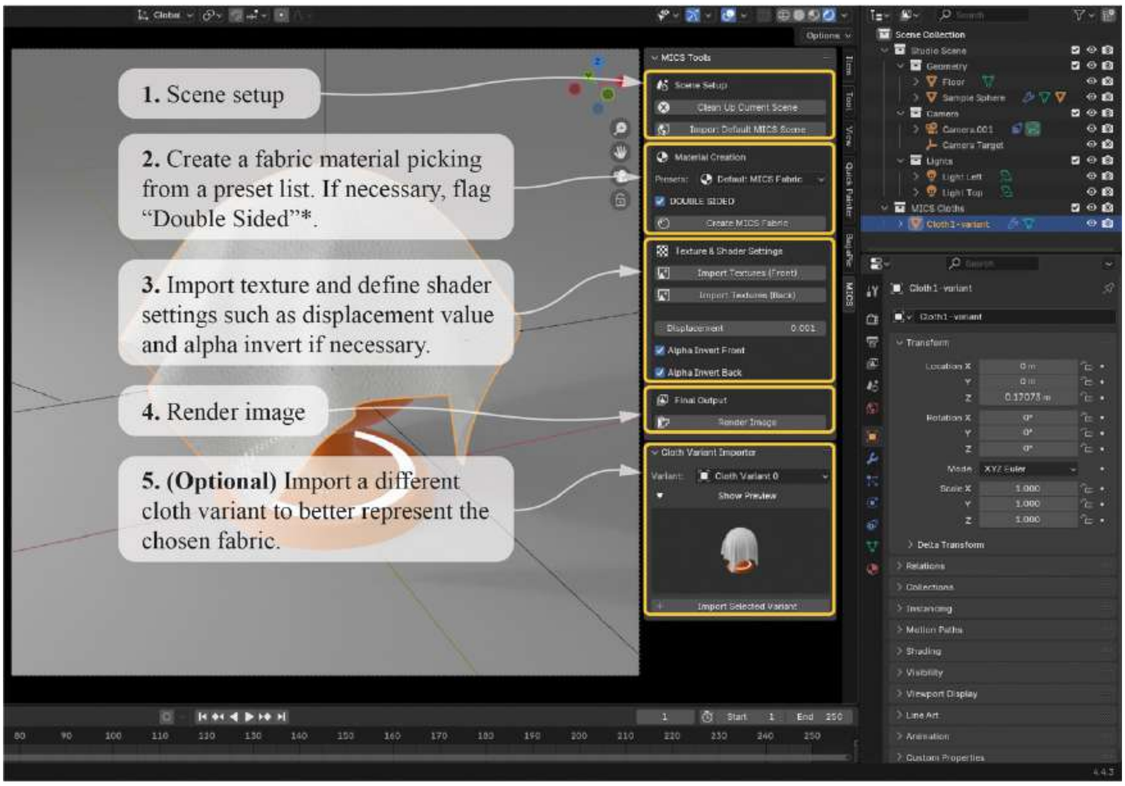

Fig. 3
Interface of the custom Blender addon. The panel guides the user through a streamlined workflow for setting up a scene, creating a fabric material from presets, importing textures, and rendering the final image. (Credits: Gaeta B. and Foschi R.)

This addon is envisioned to significantly simplify the material creation process by providing a more guided and automated interface than Blender's native node-based shader editor. It aims to offer preset material templates suitable for common textile types and a streamlined workflow for users to apply their generated texture maps. For instance, beginners could benefit from simplified controls, while advanced users would retain the ability to delve into Blender's comprehensive toolset for further customization and fine-tuning. This approach ensures that the tool is both accessible to its primary target audience and sufficiently powerful for more specialized applications, embodying a scalable system of interaction.

The overarching goal is to create a post-processing and rendering pipeline that empowers users to efficiently and effectively translate physical textiles into high-quality digital assets. By focusing on open-source solutions and developing user-centric tools like the Blender addon, the process becomes more democratized and aligned with the sustainable and circular objectives of the fashion industry. Future developments will concentrate on further automating the extraction of all necessary PBR maps and integrating seamless tiling capabilities, thereby creating an even more streamlined and accessible end-to-end workflow for textile virtualization.

REAL-TIME TACTILE INTERACTION

To support the adoption of immersive approaches during the early stages of textile ideation and design, in addition to the acquisition and transformation of physical samples into their digital counterparts, part of this project focused on the representation of outputs within a virtual environment. This effort had two goals: first, to compare the quality of the proposed acquisition method with that of existing commercial solutions; second, to investigate the perceptual impact of virtual tactile simulation on users, in order to assess its potential for remote collaborative design contexts.

Although the experimentation relied on small physical swatches, it is important to acknowledge that textile perception is inherently multisensory and distributed across the whole surface of the body, not limited to fingertip interaction. In this sense, the digital approach used in this work aims to explore the possibility of understanding synthetically simulated tactile behavior. This limitation is intentional: focusing on localized tactile feedback allows the method to remain feasible within current haptic technology constraints, while still enabling a meaningful comparison between acquisition workflows.
The Unreal Engine software was selected to develop an experimental scene, as it offered an effective balance between compatibility with outputs from Blender, integration via dedicated Software Development Kits (SDKs), and interaction with the WeArt Touch Diver haptic device, chosen both for its technical features and as a Made in Italy innovation. Furthermore, Unreal's ability to represent complex materials makes it suitable for future integration into extended workflows.
As for visual rendering and acquisition evaluation, simplicity and usability were ensured by limiting implementation to albedo, normal, and alpha maps, which proved sufficient to describe convincing virtual textures (displacement maps were excluded for real-time interaction in order to improve performances, while roughness and metalness properties were set numerically in-app). Experimental testing confirmed the accuracy of material matching between real and digital samples, regardless of whether the digital textures originated from commercial tools or the workflow proposed in this project (Zannoni, 2024) **Fig. 4**.

Fig. 4
Virtual visual-tactile experience test. (Credits: Pucci D.)

The final phase of the project focused on collecting the digitized fabric samples and relative maps, values, and coefficients, with the goal of making them accessible to stakeholders in the textile supply chain. This required the creation of a digital archive designed for both browsing and downloading virtual prototypes, as well as for uploading new materials by Made in Italy textile companies.
Digital material archives are vital tools in the designer's workflow for material selection (Ashby & Johnson, 2010). Designers often consult material libraries or innovation observatories at the start of the design process, allowing the material to influence form, function, and aesthetics rather than being a passive constraint (Karana et al., 2014). This approach—which argues that materials are not passive elements to be selected at the end of the process but generative agents that shape form, function, and experience—is known as Material Driven Design (MDD). Through an iterative exploration of sensory, technical, experiential, and contextual properties, MDD enables designers to make more informed and situated decisions, integrating performance criteria with considerations related to use, perception, and sustainability (Karana et al., 2009). This methodology is particularly relevant to the type of process developed here, as it plays a significant role in contemporary material selection practices, which are characterised by the emergence of new resources, bio-based materials, and circular solutions that require critical evaluation skills and a design approach guided by the potential of materials (Karana et al., 2015).
The transition from physical libraries to digital material databases has created new opportunities for managing, sharing, and accessing materials, while also presenting challenges in representing the tactile and perceptual qualities of physical samples. The Digital Textile Heritage Archive **Fig.5**, supported by the real-time visual-tactile interaction methodology, enhances material selection through immersive experiences, enabling users to assess surface properties, thermal sensations, and optical behavior.

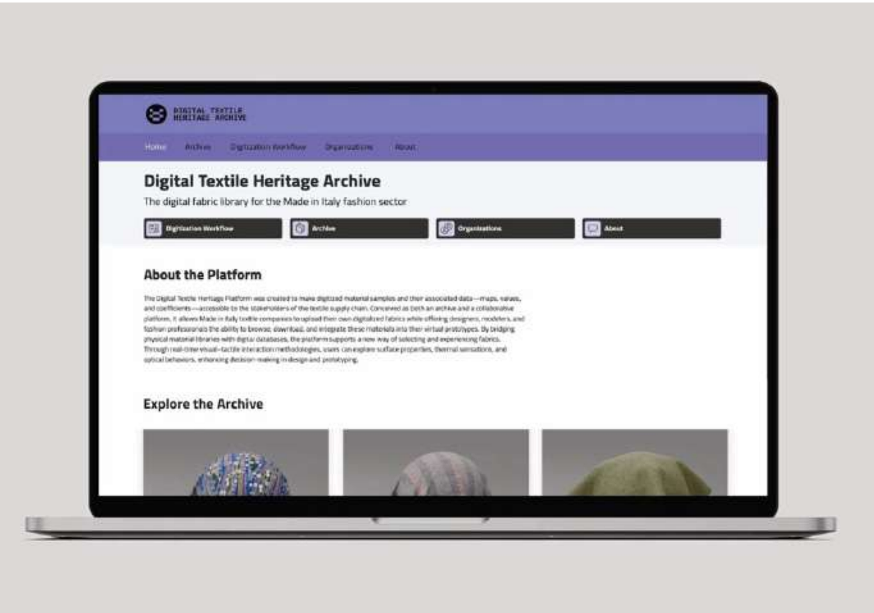

Fig. 5
Homepage of the Digital Textile Heritage Archive (Credits: Rosato L.)

The platform is intended for multiple types of stakeholders: textile producers uploading their digital models and physical performance data, and design professionals who use them in virtual modeling and prototyping. It is

especially relevant for roles within fashion brands, such as digital textile developers or 3D fashion designers.
The archive is structured into several sections: (i) description of textile acquisition and modeling methods; (ii) guidelines for real-time tactile interaction, including tools and procedures; (iii) a searchable database of digital textile materials filterable by digital or physical characteristics, or explorable via immersive browsing; (iv) a project gallery showing applications developed using the database, highlighting potential use cases and collaborations. The platform aims to support collaborative design processes by acting as a central hub for tools, practices, and actors. Its interface will include an administrative backend for companies to upload materials and a front-facing archive for designers and users. Access levels are currently under development. Thanks to their inherent flexibility, digital systems allow personalized search paths tailored to user needs. Material metadata was designed to guide prototyping decisions while also enabling contact with manufacturers for purchasing physical samples, supporting a smooth transition from prototype to production. Thus, the research reflects this dual need, connecting digital filters to physical, real-world attributes, particularly those tied to the values of Made in Italy and circular sustainability.
The registration and access system will allow users to customize search modes based on material filters or typologies and adjust these preferences dynamically during use.

APPROACHES OF THE TRANSITIONAL INDUSTRIAL DESIGNER FOR A DIGITAL TRANSITION OF MADE IN ITALY

The analysis of the experimental process allowed for the identification of specific approaches that, within the digital context, become strategic drivers of attention and innovation. By revisiting the mapping of the Transitional Industrial Designer's (TID) design attitudes see **Fig. 6**, it becomes evident that some of these, when applied to digital projects, gain central importance and evolve into core design guidelines.

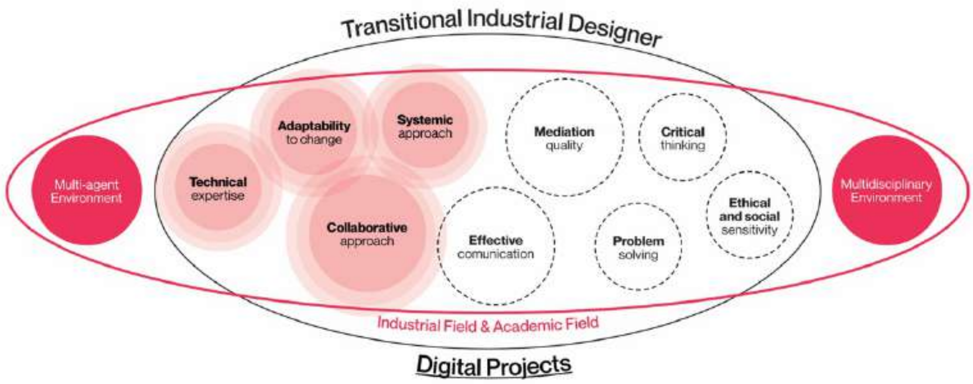

Fig. 6
Transition Industrial Designer Framework with digital projects (Credits: Authors' elaboration based on Zannoni et al., 2024).

First among these is technical expertise, as digital contexts demand strong and specific skills, such as coding, 3D modeling, scripting, rendering, and the use of AI-based tools. Designers must not only operate at a general level by

defining contexts and frameworks but also navigate finer-grained levels of complexity that enable precise mediation among disciplines. Consequently, to support innovative, integrated, and responsible development, the traditionally transversal nature of the designer's role must evolve by integrating vertical competencies, namely, deeper knowledge of languages, software, and physical tools. The second key element is adaptability to change, particularly relevant in digital, virtual, and immersive environments. These contexts are constantly and rapidly evolving, requiring prompt responsiveness to technological and methodological innovations. This implies the need to build flexible, interoperable frameworks and workflows capable of minimizing the impact of obsolescence and integrating emerging tools and theories as soon as they appear in literature or on the market. As previously noted, such adaptability is only possible through the participation of multiple actors who can manage specific complexities while understanding the broader dynamics of digital transformation. In this scenario, the designer becomes not only a mediator of both cultural and operational expertise but also a translator, capable of interpreting the language of each discipline and making it accessible to all stakeholders involved. Through active listening and mutual understanding, the designer facilitates the integration of specialized knowledge within the project. In the presented experimentation, each phase relied on contributions from various disciplinary domains and technical specialties, including virtual environments, 3D modeling, digital archiving, and photometric stereo techniques. Building a coherent and interconnected process required close collaboration among researchers and continuous mediation of knowledge. Only through this synergy was it possible to achieve a coherent, accessible, and fully integrated outcome. From this reflection emerges the centrality of a systemic approach. Managing complexity in digital projects means designing interdependent systems in which each component—technological, disciplinary, operational—contributes to a cohesive and adaptable whole. The immaterial and flexible nature of digital artifacts facilitates the integration of diverse solutions but also increases the project's complexity compared to analog systems. Thus, a robust, multilayered framework is necessary to navigate and manage evolving processes.
In our case study, the system was not structured as a linear sequence of input and output but rather as an organic system—a network of functional interdependencies. Each phase, from acquisition to modeling, interaction, and archiving, played a specific role while remaining fully integrated with the others. As in a biological system, no component can operate in isolation: the effectiveness of the whole depends on the internal cohesion and the capacity to adapt and respond as a unified entity.

CONCLUSIONS

The project described herein offered a concrete opportunity to explore the role of design as an active agent in the digital, sustainable, and circular transition of the Italian textile sector. The experimentation enabled the definition of a structured and replicable design process based on the integration of open-source tools, low-cost technologies, and immersive devices applied synergistically across the phases of acquisition, virtualization, interaction, and archiving of textile materials.
The methodological approach highlighted the centrality of the Transitional Industrial Designer (TID) as a mediator among specialized knowledge, emerging technologies, and stakeholders along the supply chain. This role

proved to be essential in ensuring the process's accessibility, coherence, and scalability, and in enabling dialogue across heterogeneous disciplines while contributing to the identification of design drivers that can inform future projects.
The analysis of the TID's role in digital contexts emphasized several key competencies: the ability to integrate highly specialized vertical expertise with a holistic and transversal vision; the capacity for technological foresight and adaptability; the inclination toward interdisciplinary collaboration; and, finally, the capability to design multilayered, interconnected systems that combine diverse functionalities into cohesive project architectures.
Together, these elements form a robust methodological foundation for tackling the complexity of digitalization processes in contemporary design practice with awareness and responsibility.
The experimentation also makes it possible to identify the range of actors who can meaningfully benefit from the proposed system. Although the workflow was primarily conceived to address the needs of textile manufacturers, its value extends to garment-making companies, which—much like textile producers—are engaged in ongoing digitalization efforts related to the management, consultation, and distribution of textile samples. The tools developed also hold potential for cultural institutions tasked with preserving and disseminating textile heritage, offering new opportunities to support cataloguing processes and to enhance accessibility to fragile or historically significant materials. In this regard, the project not only responds to immediate industrial needs but also activates broader opportunities across the textile ecosystem, enabling shared and distributed modes of material knowledge.
At the same time, the research reveals several limitations that warrant further investigation. The coexistence of digital and physical materiality continues to pose challenges: while virtualization provides an advanced representation of textures, it does not fully replace the sensory richness of physical samples and demands interpretive skills from designers and practitioners. The fidelity of haptic and visual rendering, the heterogeneous technological maturity of stakeholders, and the resource investment needed to adopt the proposed tools all represent concrete obstacles that may affect the scalability of the system. These limitations underline the need for continued development to ensure reliable integration across the textile and fashion value chain.
Despite these challenges, the experimentation demonstrates that the convergence of immersive interaction, open-source tools, and material digitization can lay the groundwork for a more interconnected, accessible, and sustainable textile ecosystem.

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DIGITAL SPECIAL ISSUE 3

This special issue of DIID brings together the broadest possible reflection on projects that, with a low Technology Readiness Level (TRL), have attempted to translate years of ongoing research within the sector towards unexplored directions, towards renewal processes framed by sustainability and circularity. All of this is pursued with the aim of enhancing the sustainable competitiveness of Made in Italy through concrete actions developed in collaboration with companies involved from the very beginning, as well as with other firms interested in the relevant themes.
The projects were developed within the following universities: Politecnico di Bari, Politecnico di Milano, Politecnico di Torino, Università degli Studi di Napoli Federico II, Università degli Studi di Palermo, Università di Bologna, Università di Firenze e Sapi-enza Università di Roma.
The overall picture that emerges from this overview of research activities is rich in in-sights and demonstrates how our scientific sector, when compared with fields that have a longer historical tradition in research, is nevertheless capable of making a significant contribution. It also shows that scientific research in the field of Design is able to generate incisive and relevant reflections and solutions for the driving sectors of Made in Italy.
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