DIGITAL ADVANCED DESIGN

TRANSITIONAL INDUSTRIAL APPROACHES FOR SUSTAINABLE INNOVATION

edited by
Flaviano Celaschi
Laura Succini
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HAPTIC PERCEPTION AND ENHANCEMENT OF THE INTERACTIVE TEXTILE XR EXPERIENCE

Michele Zannoni, Roberto Saponelli**, Diego Pucci*, Ludovica Rosato**

1. Introduction

The contribution presented below outlines the developments of the first twelve months of progress in "Project 1.2," which is part of the "Spoke 1" group,[1] encompassing projects with the goal of digitising processes. The resulting work aims to extend the possibilities offered by digital tools to make them applicable in strategic areas of Italian craftsmanship, which are currently entirely analogue and artisanal. This objective represents a significant challenge because the target sectors, namely furniture and fashion, exhibit complex dynamics, and compressed development timelines, and involve actors with highly refined technical skills and sensitivities, which are extremely difficult to replicate and satisfy. On the contrary, digital tools, due to their dematerialised nature, allow for a drastic reduction in the resources expended in the iterative processes typical of artisanal methods.

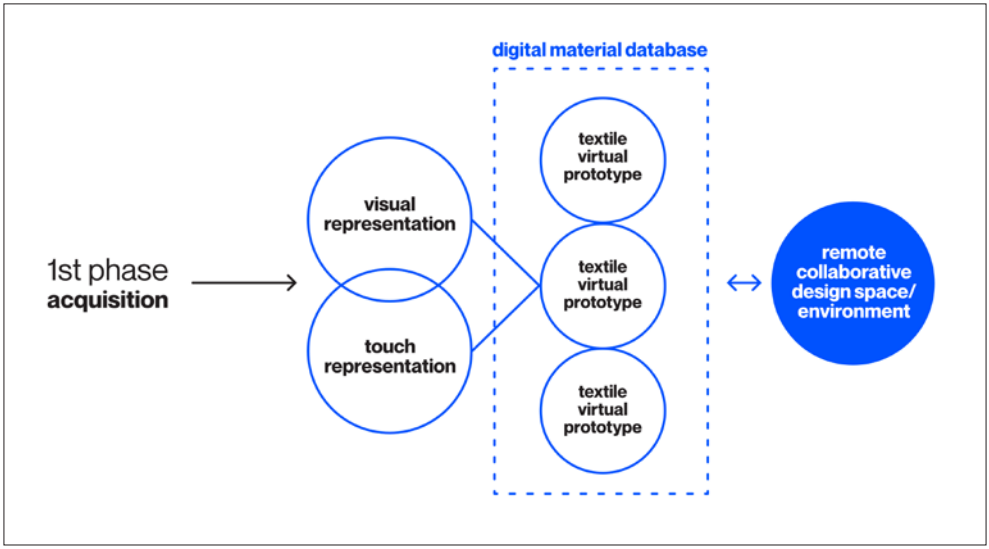
Therefore, this experimental research is founded at the intersection of the two worlds described, aiming to identify the boundary between what can be significantly simplified and virtualised in the textile world and what must remain analogue and exclusively within the domain of specialists. The work has been structured according to the workflow outlined in figure 1, which, following a dedicated acquisition phase, involves dedicated development, the subject of this progress.

2. Digital textile experiences for a circular and sustainable supply chain transition

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In the process of material selection for textiles, the introduction of interactive digital experiences, for the fashion or furniture



1. Activities carried out within Project 1.2. All images are reproduced in color in the online edition of the book.

system, allows the creation of new sustainable and circular design possibilities for impact-critical fields of application.

The fashion system is characterised by a process of pre-production, production, distribution, use and disposal that produces harmful environmental and human impacts (Vezzoli et al., 2022). The fast fashion supply chain negatively impacts the use of water, land and resources by actively participating in climate change (European Environment Agency, 2022); it accounts for 3 to 10% of global emissions and, in Europe, is estimated to lead to the production of 15 kg of textile waste per person per year, with 85% of the total coming from post-consumer textiles (McKinsey & Company, 2022, p. 13).

However, textile waste is also generated in the pre-production phase, from the acquisition of resources through to their transformation into materials and into clothing products. The selection process of a material takes place in the pre-production phase and contributes differently to the production of emissions (Pellizzari & Genovesi, 2021). The prototyping phase involves physical sampling of the model to be put into production, for which the apparel industry invests between 5 and 7 billion pounds annually (Roberts-Islam, 2019). This sampling phase results in the creation of prototypes that are assembled and photographed for trend projection and evaluation. Brands and retailers continually require the creation of hundreds of new mock-ups which, inevitably, have a short shelf life and most end up being incinerated or disposed of in landfills, participating in the production of supply chain waste.

The distribution of samples also has an environmental impact in terms of transport, packaging and all sales and storage activities by suppliers (Vezzoli et al., 2022). The environmental impact of transport can vary according to the distance of the journey and the means of transport used; that of packaging according to the waste produced by primary, secondary and tertiary packaging. Overall, the environmental effects at this stage include the depletion of fossil resources, climate change, human toxicity due to air pollution and winter smog (Vezzoli et al., 2022). In the furnishing system, which is particularly critical in terms of transport related to product weight, Cerulo et al. (2022) suggest reducing these impacts by preferring local materials and solutions while minimising transport or identifying

transport solutions with minimal pollution by avoiding planes and trucks.

In Italy, this type of impact, applied to the Made in Italy system for fashion and furniture, is often limited by district policy and, therefore, the proximity of sub-suppliers in the entire production chain. However, when it comes to textile sourcing, this proximity is not always possible as their production is international (Textile Exchange, 2022).

Digitising the pre-production process, starting with the design and selection of the material is an action that could therefore offer a net reduction in resource use and textile waste production (Roberts-Islam, 2021).

3. Haptics and applied immersive experiences: State of the art

The digitalisation of processes is a practice in continuous expansion, particularly in the last two decades, where this phenomenon, taking advantage of highly sophisticated touchpoints resulting from advanced studies and experiments, has gained favour with specialised audiences. This allows for a reduction in the time needed to perform activities while simultaneously containing costs in terms of human and material resources. This refers to enabling technologies that can be broadly categorised into four families: data-driven, execution-driven, organisational-driven, and simulation-driven (Qi et al., 2021). For the project presented here, the last family, which includes outcomes related to extended reality and, in particular, virtual reality, is of interest in the context of digitalising processes performed prior to production.

The approach of virtual reality, or VR, finds application in many fields: advanced visualisation contexts (El Beheiry et al., 2019), customised configuration (Bachvarov et al., 2017), and procedure simulation (Van Campenhout et al., 2020), supporting evaluation activities and facilitating selection processes. These are always forms of representation; however, in each field, the virtual agent enhances different characteristics. A notable example is the presence and increased comprehensibility of structures or the intelligibility of data by using scenes and inputs familiar to the user (Lee et al., 2020).

The project therefore aims to embrace the various intrinsic advantages of using virtual environments, primarily taking advantage of the extreme ease of modifying elements and surfaces within the scene, the safety of a risk-free simulated environment since it is fictitious and, finally, the minimisation of the loss of representativeness of human-object interaction, which is crucial when it comes to fabrics and derivatives in the fashion and furnishings sectors.

Having defined the intention to deepen the relationship between design experiences in the textile field and virtual environments, the research team questioned which aspects should be the focus of their efforts. On one hand, the need emerged to identify a low-budget acquisition flow that would allow for the capture of physical samples and the production of high-fidelity virtual counterparts. On the other hand, the perception of virtual materials became a particularly interesting topic, as in the textile world, specialists cannot do without direct and tactile interaction with the materials they intend to use. In this regard, during the investigation of the state of the art, a significant emphasis was placed on haptics, meaning the ability to "feel" materials through touch and the related systems and devices necessary for their simulation and the digital definition of their contours (Ceccacci et al., 2023).

This landscape offers multiple insights and solutions to add a physical dimension to experiences that are otherwise intangible by nature, thus manifesting a common goal of impressing stimuli on the users' skin and receptors that add meaning to the experiences. As a result, commercial products are emerging, typically in the form of garments (with vests, gloves, and helmets being the most common), capable of generating forces, pressures, and vibrations that resist or otherwise respond to users' actions. Alongside these options, various prototypes are being developed that aim to enhance the definition and precise manipulation of virtual objects (Ninu et al., 2013) or specialise in the representation of volumes and interactions in extended spatial environments (Gomi et al., 2024). In any case, the proliferation and progress observed demonstrate the potential and subsequent interest in this field.

Based on these findings, the possibility of introducing such qualities into the project immediately seemed intriguing, as it

represents not only an additional level of complexity but also a multiplier of the value and representativeness of the experience. This is evidenced by the work of (Ornati & Kalbaska, 2022), who used this approach to enhance the remote fruition of textile products during the COVID-19 pandemic. In this project, however, thanks to the ability to personally manage the acquisition process, the idea was to develop a workflow aimed not at the communication and distribution of products but at their actual design, to provide valuable support to designers during the ideation phase.

4. Interactive textile XR experience

4.1. Methodology

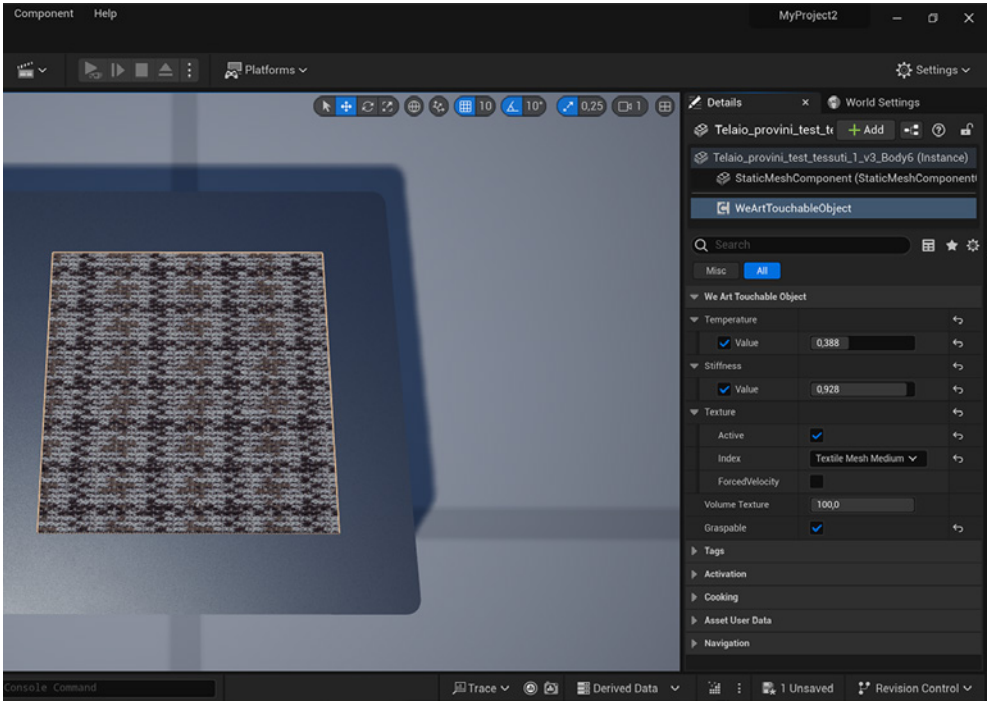
Starting from the project's ultimate goal, creating a set of advanced digital tools that support remote collaborative design processes, the target outputs to be achieved and the series of operations and activities necessary to reach them were defined. Three outcomes were hypothesised for the virtual design environment, which differs in complexity and priority within the developing workflow: the first involves inheriting the acquired virtual samples and categorising them in an archive potentially significant for stakeholders at the end of the process (fabric manufacturers, designers, and brands that market products containing the fabrics handled by the previous actors); the second, implementing tactile simulation parameters in the virtual textile models (figs. 2-3); and finally, following a specific experimental campaign, the definition of guidelines for the good design of remote collaborative design environments and contexts.

In the first half of the project, priority was given to the first two aspects, the details of which are the subject of the continuation of this contribution. In summary, following the first phase of research, a benchmark of possible software and hardware was conducted in parallel to study and design virtual experiences sufficiently effective, in line with the original project hypothesis, along with a field-specific verticalisation on the technical skills of the textile world, which was essential for preparing an archiving architecture consistent with the sector's needs.

2. Real textile sample.



3. Virtual Haptic textile counterpart.



User perception is a key issue in the selection of materials: it is the result of the interpretation of what is observed (Ashby & Johnson, 2010) and memory plays a key role as it records man's relationship with matter as it is transmitted to us (Manzini, 1986). Everyone has a different perception of the object based on his or her reaction to the physicality of the artefact and previous mental images of previously accumulated experiences (Ashby & Johnson, 2010). The perception and memory of material are formed from different characteristics that the object expresses: expressive sensory, association, perceptual and emotional, and technical functionality. The sum of these parameters forms the personality of a product (Ashby, 2010). The Material Experience (Karana et al., 2014), understood as the experience users have with materials through expressive-sensory characteristics, can be one of the variables of perception and personality of a material.

Understanding how to transition this experience into digital, translating the perceived characteristics into a comprehensible language and positively influencing its selection, is therefore a key variable in our design process.

While bringing this experience to XR and during the selection of material samples, an attempt was made to identify which parameters could be representative and in what way. Then, if we are talking about circular and sustainable materials for which research is directing its choices in the textile field but which, being many in the research phase, do not always have a recognisable material personality (Rosato, 2023).

The tests carried out so far simulate two main characteristics of the selection of fabric: temperature and touch sensation, allowing the perception of the "hand of the fabric." In particular, the haptic glove[2] used in the experiments makes it possible, through vibration and pressure, to simulate the sensations produced when a textile surface is handled through touch by running the fingers over the surface itself.

These two features are the first parameters studied and subsequent simulations of immersive experiences are being evaluated and studied.

4.2. Experimentations

To verify the perceived quality of the visual and tactile rendering of virtual fabrics, two test sessions were conducted, provid-

ing initial indications regarding the level of engagement of the virtual experience and the first ideas for reflection and modification.

The process of creating the experience evolved from the selection of fabric samples, choosing a range of options that balanced complexity with the fineness of the textures and the type of acquisition, whether through a commercial procedure (xTex Website, n.d.) or the workflow that is part of this project. Subsequently, a virtual scene was created, containing a frame that included the samples chosen for the test, and then the physical testing environment was set up, consisting of a computer, virtual headset, haptic glove, and real samples; figure 4 shows the setup.

The first series of preliminary tests involved seven non-professional figures with good experience and familiarity with the use of virtual tools, in order to speed up the selection of the most understandable experience flow and gather clear technical feedback and input to implement (Zannoni et al., 2024). In this first phase, it immediately became apparent that the different acquisition processes were not perceived as different by the testers, highlighting that the visual rendering of the samples is comparable and of good quality, at the point of influencing significantly the process of association between real and virtual samples.

Following the necessary implementations, the virtual scene was presented to another twenty testers, again non-professionals, without proven experience and familiarity with digital tools. Specifically, the participants were divided into two groups, with the common goal of associating the touch of the virtual material with the corresponding real fabric sample. The first group experienced a virtual scene where the virtual samples were visually identical and tactilely differentiated, while the second group's experience included both tactile and visual differentiation.

5. Discussion

The experimentation, representing the culmination of the work done so far, has yielded positive results in terms of understanding the scene and experience, demonstrating a good level of engagement and presence among the participants. However, the



4. Hardware test environment.



5. Association test between physical samples and digital ones without visual texture.

results did not fully validate the restitution process, underlining that there is still much work to be done in both the design of experiences and the technological refinement of tactile stimuli. On the other hand, the results are encouraging as they show the success of the acquisition procedure and demonstrate the feasibility of the remote collaborative design environment.

Summarising the findings from the investigation, the impact of visualisation is extremely relevant despite the focus being on touch. In the two groups studied, the percentage of correct associations between the virtual and real samples was significantly higher when the digital counterpart was visually textured, confirming the good usability of the acquisition output and that the visual-tactile virtual experience is converging, suggesting a reasonable representativeness of the system, as shown in figure 5. Another interesting factor that emerged is the impact of the testers' familiarity with the tools used. As initially hypothesised, those more accustomed to tactile stimuli generated by smartphones and gaming joysticks showed greater sensitivity and responsiveness to the haptic simulation used. The simulation still requires further implementation since the correct associations were derived from comparisons with only one real sample at a time, indicating that an unambiguous convergence between the real and digital textures has not yet been achieved, which remains a priority topic for further exploration in the project.

Other implementation fronts mainly involve conducting a couple of counter-tests to serve as a filter for a more nuanced and informed interpretation of the data collected so far. Specifically, a plan is in place to conduct the same test described previously with an additional variant, namely the association between real touch and only virtual visualisation, in order to determine whether the better results obtained when the virtual samples were differentiated are solely due to vision or if the tactile enhancement actually contributes to recognisability. Finally, there is also an intention to perform a test with expert specialists whose touch sensitivity is particularly well-trained, to understand whether the limited recognisability of the current tactile patterns is indeed lacking and thus requires a drastic rethink of the representation or if it involves minor variations that still need fine-tuning.

6. Conclusion

The experiments developed so far are preparatory to the realisation of the digital material database (fig. 1). This product aims to collect the digital models of textile samples of the Made in Italy companies in order, on the one hand, to facilitate the selection of materials to the operators of the supply chain through a platform that collects and archives the products in an organised way, and, on the other hand, to obtain the models for virtual prototyping. Moreover, the integration of the virtual fabric handling experience enables operators to obtain a complete material selection method, from the analysis of the technical characteristics communicated in the database, to their sensorial experience through XR, to their use for virtual prototyping.

The digital material library is a work in progress; to date, the research has traced the needs of the territory, both through desk research that helps to define the storage methods of physical fabrics and the corresponding digitisation methods, and through the mapping of the territory's supply chain, in order to highlight which actors and at what stage they enter into communication with the platform. Moreover, through field research, we involved local companies, and possible users of the service, in order to map and collect their needs both in terms of how to acquire and disseminate fabrics and in terms of end uses of the platform.

Notes

[1] Internal coding within the extended MICS partnership, which oversees the projects related to the "Made in Italy Circular and Sustainable," funded by PNRR national project.

[2] The device adopted for the virtual tactile representation of fabrics is the "WeArt Touch Diver," selected due to the good ratio between the range of stimuli it can generate and the complexity of the process. Additionally, the manufacturing company, based in Milan, reflects the Made in Italy character of the project.

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